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TECHNICAL MEMORANDUM V

EVALUATION OF COVER AND STRUCTURE STABILITY ON THREE GENERIC CANADIAN URANIUM TAILINGS SITES

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THE STABILITY OF CONTROL STRUCTURES FOR URANIUM MILL TAILINGS

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MICROMEDIA

PREFACE

This technical memorandum is the last in a series of five technical memoranda which document the data, technology and evaluation studies undertaken to evaluate the long term stability of "Covers" and "Control Structures" for Canadian uranium mill tailings. The technical memoranda are:

Technical Memorandum	Title
TMI	Canadian Uranium Tailings Deposits and Structures
TMII	Characteristics Relevant to Releases of Three Generic Canadian Uranium Tailings Sites
TMIII	Methodology for Stability and Release Rate Evaluation
TMIV	Assessment of Alternative Evaluation Methods and Alternative Stabilization Practices
TMV	Evaluation of Cover and Structure Stability on Three Generic Canadian Uranium Tailings Sites

The conclusions reached and observations made as a result of these studies are summarized in two reports entitled:

REPORT 58901 THE TECHNOLOGY OF URANIUM TAILINGS COVERS

REPORT 58902 THE STABILITY OF CONTROL STRUCTURES FOR URANIUM MILL TAILINGS

This technical memorandum describes the evaluations done on the long term stability of three generic Canadian uranium tailings sites. The generic site characteristics are derived from the descriptions of the sites described in TM II. Characteristics of the generic sites, while typical of actual sites are modified to allow evaluation of a wider range of long term stability concerns under a number of reclamation scenarios and do not reflect evaluations of any actual Canadian deposits.

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This study was guided by the Scientific Authority, Mr. Grant Feasby, and his prompt and effective guidance, review and comment contributed largely to its successful completion.

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TECHNICAL MEMORANDUM V: EVALUATION OF COVER AND STRUCTURE STABILITY ON THREE GENERIC CANADIAN URANIUM TAILINGS SITES

V.1.0 EVALUATION OF COVER STABILITY

V.1.1 INTRODUCTION

In this Technical Memorandum the long term stability of the three generic Canadian uranium tailings sites, described in Technical Memorandum II, is evaluated. The three generic tailings sites considered represent:

(i) a tailings site typical of many of the tailings impoundments and deposits in the Elliot Lake, Ontario area,

(ii) a tailings site with embankment and deposit characteristics which would be typical of a Saskatchewan deposit in which tailings had been placed using conventional spigot and mass discharge "wet" placement methods,

(iii) a tailings site with embankment and deposit characteristics typical of a Saskatchewan deposit in which tailings had been placed in a managed layer sequence to achieve maximum dewatering or "semi-dry" tailings.

This evaluation represents the last phase of a three month multi-disciplinary study which ranged from the data collection required to describe the existing Canadian uranium tailings deposits, identification of long term stability concerns pertinent to Canadian conditions through an evaluation of the available technology for such evaluations and its application to Canadian conditions.

Time constraints have limited the extent and depth of technology evaluation. In particular, little or no re-assessment or re-evaluation could be done following input from industry or other interested parties. It has not been possible to check the conclusions reached with actual field experience except to the extent that such field information was already available to the study team.

It is likely that instability at tailings impoundments will result as a combination of factors. Examples may be:

(i) debris blockage of a riprap protected drainage channel (spillway) causes flooding resulting in gully erosion initiating adjacent to the channel causing the channel to be undermined and the riprap to fail. Additional erosion of the now unprotected channel results in deep gully erosion of the embankment and tailings.

(ii) Severe freezing causes blockage of the outlet drains from the toe drain of an embankment. This results in high seepage gradients which produce piping failures (seepage erosion) and minor slumping of the toe of the embankment. Slumping destroys the toe drainage system causing permanent blocking of the underdrainage system. A sequence of piping and or embankment slumps follow as a result of the high

pore pressures in the toe of the embankment. The progressive failure then spreads both along the embankment and back into the impoundment.

(iii) Following a severe drought, a forest fire results in the temporary loss of vegetation cover on a successfully revegetated sulphide tailings impoundment. A period of high winds follow, resulting in significant wind erosion on one area of the impoundment before the vegetation recovers. Upward migration of salt occurs in this bare area where previously the effect of vegetation (and hence infiltration) prevented such migration. The salt migration and wind erosion combined, effectively inhibit regeneration of the vegetation. Continued wind and water erosion results in the release of tailings.

There is a vast combination of events which can be postulated which may result in instability. Additional combinations as well as probability techniques for their evaluation are discussed in sections III.9 and IV.6 of TMIII and IV, respectively. Within the limits of this study it has been possible to evaluate only some of the postulated contributors to such failures. Further, the differences between stable and unstable conditions are often unclear and speculative. Examples are:

(i) Whether aggrading or degrading frost conditions will exist in a tailings impoundment with particular tailings and cover properties in northern Saskatchewan. The result has a large effect on cover stability.

(ii) Rates and effects of salt precipitation (in underdrains) from a salt saturated tailings solution subject to changing chemical environments resulting from oxidation in the partially saturated underdrains.

(iii) The viability of vegetation in the long term on sulphide tailings with thin soil and the potential for upward salt migration.

In many instances the current state of knowledge is either insufficient or the technology or the data is insufficiently precise to permit long term evaluations with acceptable or realistic accuracy. Such evaluations are effectively no more than speculation. In the interest of providing some measure of the long term stability of tailings impoundments, and identifying the areas of concern, the study team have attempted to extend the evaluations well into the zone of speculation.

It is important that the reader should recognize the speculative nature of many of the long term evaluations. Improvements in the state of knowledge and technology will undoubtedly improve the accuracy of evaluation and prediction and reduce the need for speculation.

V.1.2 STABILITY OF VEGETATION COVER

The physical characteristics of the tailings impoundments and covers evaluated here are described in Technical Memorandum II. For the sake of brevity this subsection indicates the conclusions reached and makes recommendations in point form.

V.1.2.1 Typical Tailings Site, Ontario

V.1.2.1.1 No Cover

(i) No Action:

The concept of no reclamation measures after drainage of the head pond would appear to be unacceptable. Development of acid conditions could prevent the development of a natural vegetative cover for many hundreds of years (see IV.1.6.1).

(ii) Contour and Direct Vegetation:

At present the implementation of this option may not be feasible. Direct seeding of newly deposited tailings has not been investigated. Other experience (nickel and copper tailings - see section IV.3.4) indicates that a one to three year "maturation" period is required before vegetation can be established directly. Within that period it is possible that pyrite within the tailings will begin to oxidize. Research is required to determine if chemical additions to the tailings, e.g. limestone, phosphates or silicates will prevent or retard pyrite oxidation until such time as the tailings are amenable to revegetation. Additional research is required to determine if a chemical treatment and revegetation interaction will provide permanent inhibition of pyrite oxidation.

(iii) Contour with Pyrite Free Tailings and Direct Vegetation

a. The point in time after deposition of the pyrite-free tailings at which they can be vegetated has to be determined.

b. If a lag phase is required, interim surface erosion control will be necessary. This may include chemical stabilization or use of windscreens for wind erosion control; the use of a mulch (e.g., stone or organic-type) to prevent sheet, rill and gully erosion.

c. Long term stability of vegetation established on pyritic-free tailings will be partly governed by the ability of the pyritic-free layer to prevent pyrite oxidation in the underlying mass of pyritic tailings, with consequently, no potential for upward migration of acidity and salts into the vegetation bearing layer of tailings.

d. Vegetation stability could also be affected by the contour of the surface over which the pyritic-free tailings are placed. Uneven surfaces could lead to subsurface "ponding" or "perched water" tables (on underlying slimes zones), which could effect persistence of permanently saturated subsurface location. Should ponding periodically reach the surface then the vegetation cover may be lost.

V.1.2.1.2 Thin Cover

(i) Contour, Soil Cover and Vegetation

a. A legume-grass seeds mixture can be established directly onto the silty sand till soil cover.

b. Prior to emplacement the soil cover should be evaluated for its agricultural limestone requirement and for the amount of fertilizer that should be applied to raise its nutritional status to an acceptable level.

c. Normal agricultural materials application and seedbed preparation should be undertaken prior to seeding. Seeding should be carried out in the period late May-end of June.

d. If soil cover placement is undertaken in summer or fall, interim surface erosion control would be required over the winter period, unless final fine surface grading was undertaken prior to seeding in the following year.

e. Long term persistence of vegetation established on the soil cover will be governed by non-occurrence of pyrite oxidation in the underlying tailings and/or the absence of upward migration of acidity and salts should pyrite oxidation occur (see also V.1.2.1.1(iii)(c)).

(ii) Contour and Waste Rock

a. Although this option does not call for the deliberate establishment of a vegetative cover thereon, it is anticipated that natural indigenous vegetation will colonize the well graded, competent, minus 250 mm waste rock material.

b. The degree of vegetation establishment and long term persistence will be governed by the effect of the relatively thin cover layer in preventing pyrite oxidation in the underlying tailings. If pyrite oxidation is not controlled, it is believed that upward migration of acidity and salts will likely occur, given the graded composition of the cover material. Such upward movement would be detrimental to vegetation establishment by natural indigenous species.

(iii) Water Cover

a. Direct vegetation establishment is not an option for this form of alternative technology.

b. The 0.6 m depth of water cover is sufficient to prevent pyrite oxidation in the covered tailings, and the development of aquatic vegetation communities may be expected to occur around the perimeters of the flooded tailings area. The greatest concern with a thin water cover is the natural seasonal variation in water depth. Fluctuation of water cover over a

beach area may result in instability of vegetation in that zone. Wave action in zones not stabilized by aquatic vegetation will mobilize and redistribute some of the tailings. Since there is no influx of additional sediments into the tailings disposal area it is most unlikely that the communities will become extensively developed.

V.1.2.1.3 Thick Cover

(i) Homogenous Cover

a. A legume-grass seeds mixture can be established directly into the silty-sand till soil cover placed to a 3 m depth.

b. Pre-emplacement cover analysis, surface preparation, seeding and surface erosion control procedures have already been described in V.1.2.1.2(i) a, b, c and d.

c. Vegetation stability is unlikely to be affected by any subsurface ponding or perched water tables formed, due to uneven contours, at the interface of the soil cover and tailings.

d. The depth of soil cover would be conducive to the development of a forest cover similar in height, if not complete floristic representation, of that occurring naturally in the Elliot Lake region. Provided that the soil cover is properly placed, there would be no effect of soil depth in restricting tree root growth.

e. Soil cover placement would have to be undertaken in a manner that ensured that no compacted layers occurred from excessive traffic movement as the material is emplaced. The presence of compacted layers would be detrimental to tree growth (see Section III.5.1) not only from compaction per se but also from the impedence of free drainage which could lead to poorly drained and poorly aerated subsurface areas.

(ii) Layered Cover

a. It is unlikely the surface layer of glaciated sand-gravel mixture would be detrimental to the establishment of legume-grass mixture (see Section IV.1.2); provided that the proposed standard evaluation and seeding procedures (see V.1.2.1.2(i) a, b, c and d) are undertaken.

b. If the sand-gravel mixture cover exhibited free drainage to depth, then long term persistence of the legume-grass mixture and eventual colonization by indigenous local shrubs and trees would occur. The presence of a low permeability layer though, one metre below the sand-gravel surface could have both short and long-term implications for vegetation development.

c. The presence of a low permeability layer restricts free drainage. As discussed in Section IV.1.6.3, the presence of such a layer can cause wide fluctuations in soil moisture in the layer above, depending upon May-September precipitation levels in any year. Soil moisture can range from the category of being excessively well drained to that of heavily impeded drainage (saturation and/or surface ponding). The wide range in soil moisture that can occur from year to year, therefore creates extreme soil moisture stress conditions which in turn will place stress on establishing vegetation. Such stress will markedly influence the number of species that can establish in the soil cover and will also effect the rate of growth of those species and extend the time required for the establishment of a forest type vegetation cover.

d. The potential formation of hardpans where coarser cover materials overlay a finer material has been discussed previously (Section IV.1.6.3). Development of a hardpan over time would accentuate the stress factors acting on root development and still further retard the development of a forest type cover.

e. Prior to the implementation of the alternative cover option, a water balance study in the form previously described (Section IV.1.6.3) should be undertaken in order to determine if the design of the cover option should be altered so as to allow a satisfactory level of long-term vegetation development and persistence.

(iii) Water Cover

See V.1.2.1.2(iii) Water Cover. With a thick water cover the potential for seasonal depth fluctuations resulting in tailings exposure is reduced as is the potential for tailings redistribution as a result of wave action.

V.1.2.2 Wet Tailings Site, Saskatchewan

V.1.2.2.1 No Cover and Direct Vegetation

a. An evaluation of the biological potential of the wet tailings is required before direct vegetation can be confirmed as a feasible option.

b. Should the biological potential of the wet tailings for direct seeding be proven (as is anticipated), then direct seeding would be considered a potential option for surface erosion control and long-term stability of the tailings disposal area.

c. The point in time after final deposition of tailings at which they can be vegetated has to be determined. If it is found necessary to have a 1 to 3 year time lag between final deposition and time of vegetation, then temporary

surface erosion control methods may have to be utilized (see Section III.3.4).

d. It has to be determined if direct vegetation should involve the use of agronomic species only, native species only or a combination thereof. In all three cases it is considered that a form of regional forest will establish in time as there appear to be no other inherent barriers to plant community development such as restricted rooting depth or excessively fluctuating water table.

V.1.2.2.2 Thin (600 mm) Cover of Soil or Waste Rock and Direct Vegetation

Soil

a. The placement of a 600 mm cover of local soil material over the tailings would be considered a potential option for ensuring the long-term stability of the tailings area.

b. The proposed depth of placement is considered sufficient to permit adequate herbaceous and shrub root development. As the tailings contain no pyrite, the problem of subsequent pyrite oxidation and upward migration of acidity from the tailings into the soil cover does not occur. Plant growth would only be affected if saline conditions exist in the tailings.

c. Prior to emplacement the soil cover should be evaluated for its agricultural limestone requirement and for fertilizer requirements to raise its nutritional status to an acceptable level. That status will be partly determined by the decision to use agronomic species only or native species only or a combination thereof as the initial vegetative cover to provide surface erosion control.

d. Whatever type of initial vegetation is established it is considered that a forest-type vegetation will evolve on the soil cover which will ensure long term surface stability.

Waste Rock

e. The placement of a 600 mm cover of local non-pyritic waste rock over the tailings would also be considered a potential option for ensuring the long-term stability of the tailings area.

f. Although this option calls for the direct vegetation of the waste rock surface, direct vegetation is not considered a necessity. The waste rock layer will contain a range of sized soil-sized particles as well as

coarser material. The layer itself will provide wind and water erosion control. It is considered that the surface of the waste rock layer will be naturally colonized by indigenous species adjacent to the tailings area. Plant succession processes will then determine the type and extent of forest cover that will develop over time.

V.1.2.2.3 Thick Cover (3000 mm) Consisting of Common Fill and Bedrock Waste

a. A vegetative cover chosen from agronomic or native seeds mixtures or combinations thereof is a feasible option for establishment on the common fill-bedrock waste tailings cover.

b. Pre-emplacement cover analysis, surface preparation, seeding and surface erosion control procedures have already been described in V.1.2.1.2(i) a, b, c and d.

c. Vegetation stability is unlikely to be affected by any subsurface ponding or perched water tables formed, due to uneven contours, at the interface of the soil cover and tailings.

d. The depth of soil cover would be conducive to the development of a forest cover similar in height, if not complete floristic representation, of that occurring naturally in the northern Saskatchewan region. Provided that the soil cover is properly placed, there would be no effect of soil depth in restricting tree root growth.

e. Soil cover placement would have to be undertaken in a manner that ensured that no compacted layers occurred from excessive traffic movement as the material is emplaced. The presence of compacted layers would be detrimental to tree growth (see Section III.5.1) not only from compaction per se but also from the impedence of free drainage which could lead to poorly drained and poorly aerated subsurface areas.

V.1.2.2.4 Thick (3000 mm) Zoned Cover (Table II.3.4-2)

a. A vegetative cover chosen from agronomic or native seeds mixtures or combinations thereof is a feasible option for establishment on the 500 mm soil surface layer of the thick zoned cover.

b. see V.1.2.2.3 b.

c. see V.1.2.2.3 c.

d. While the depth of soil cover is relatively shallow in terms of long-term tree root development, the underlaying layer of waste rock (100% < 30 mm; 5% < 75 microns) would

not be considered a rigid barrier to root development therein and would therefore be exploited by tree root systems. Because of the free draining characteristic of the waste rock layer, subsurface ponding or formation of perched water tables would not occur. Extended saturation of the 500 mm soil surface layer is therefore unlikely to occur (see Section III.5.1).

V.1.2.3 Semi-dry Tailings Site, Saskatchewan

V.1.2.3.1 No Cover and Direct Vegetation

a. Direct vegetation of semi-dry tailings is not considered a probable option at the present time. It is postulated that the nickel and arsenic concentrations in the tailings could represent a chemical factor preventing vegetation establishment. Acid generation and other considerations may also dictate the need for a cover layer.

b. It has been discussed elsewhere that chemical analysis of tailings is not an accurate indicator of tailings revegetation potential (Section III.2.7). Until an evaluation of the biological potential of semi-dry tailings has been undertaken (i.e., a controlled environment study) it is not possible to accurately assess the potential for implementing vegetation options which depend on vegetation growth into the tailings.

(N.B. The biological potential assessment should determine a) whether or not there is a potential and b) if there is a plant growth potential, the adaptability of agronomic and native plant species, soil amendment requirements and fertilizer requirements.)

V.1.2.3.2 Thin 600 mm Till Cover

a. A thin cover of 600 mm of till over semi-dry tailings would be considered a practical option on which an herbaceous, shrub and tree cover could be established, provided that the underlying tailings do not contain phytotoxic concentrations of nickel and arsenic. Such concentrations would prevent root penetration of the underlying tailings, as well as being a possible source of upward salt migration into the soil cover.

b. Other aspects of cover placement and type of forest cover development are presented in V.1.2.2.2.

c. Concerns regarding acid generation and salt migration are similar to those applicable to the Elliot Lake tailings discussed in Section V.1.2.1.2(i)e.

V.1.2.3.3 Thick Cover (3000 mm) of Common Fill

The placement of a 3000 mm cover of common fill over the semi-dry tailings would be of sufficient depth that contamination by upward movement of nickel and arsenic should not occur, especially when a vegetative cover has been established on the surface.

Other aspects of vegetation establishment and persistence on the thick till cover are outlined in V.1.2.2.3.

V.1.2.3.4 Thick (3000 mm) Zoned Cover (Table II.4.4-3)

The establishment of a vegetative cover and long-term development and persistence of a forest cover is considered to be highly feasible.

Other aspects of vegetation establishment and persistence are outlined in V.1.2.2.4.

V.1.3 WATER EROSION

Sheet, rill and gully erosion release rates were determined by using the following predictive methods:

1) Universal Soil Loss Equation
2) Modified Universal Soil Loss Equation
3) Gully Incision Method, (Falk et al, 1985)

Details on each of these methods are presented in Technical Memorandum IV.

V.1.3.1 Typical Tailings Site, Ontario

Details on the typical tailings impoundment have been presented in Chapter II.2.0 of Technical Memorandum II. A plan of the site is presented in Figure II.2.1-1.

The impoundment covers an area of 160 ha. No diversion channels are located upstream of the impoundment surface and a forested area of about 200 ha drains onto the impoundment. The diversion channel shown drains Lake C and associated catchment towards Lake B which drains eastwards.

The following cover alternatives have been proposed:

1) No Cover

    a) No actions
    b) Contour and direct vegetation
    c) Contour and place pyrite free tailings on the top 1 m

2) Thin Cover

    a) Contour plus 0.6 m of till plus vegetation
    b) Contour plus 0.6 m of waste rock
    c) Water layer of 0.6 m

3) Thick Cover

a) Contour plus 3 m of material
b) Contour plus 1 m of soil overlying 1 m of low permeability soil which overlies 1 m of fill
c) Water layer of 2 m

For the purpose of the analysis it has been assumed that the average slope of the cover will be 0.5% and that there will be no water or wind erosion if a water cover is used.

Average annual sheet and rill erosion was estimated by the USLE. The rainfall erosion factor, R, was estimated by using equation IV.3.5. From the available information it was established that the 2 year, 6 hour rainfall is 35.7 mm and the average annual rainfall during the period from December to May was estimated as 330 mm. The rainfall factor was calculated to be about 60.

The soil erodibility factor, K, for the different cover materials was determined by using the nomographs presented as Figures IV.3-2 and IV.3-3. Basic input parameters for the tailings and till materials were:

1) Tailings:

a)	% silt + % fine sand:	100	percent
b)	% sand:	0	percent
c)	soil structure:	1	
d)	permeability:	3	
e)	organic matter %:	0 to 2	percent

2) Till:

a)	% silt + % fine sand:	30	percent
b)	% sand:	50	percent
c)	soil structure:	2	
d)	permeability:	4	
e)	organic matter %:	0 to 3	percent

3) Waste Rock:

a)	% silt + % fine sand:	0	percent
b)	% sand:	15	percent
c)	soil structure:	4	
d)	permeability:	1	
e)	organic matter %:	0 to 2	percent

The K factor for the tailings, till, and waste rock materials were estimated as 0.8, 0.25, and 0.05 respectively.

The LS factor was calculated from Equation IV.3.6. The average length was estimated as about 1000 m (3000 ft) and the average cover slope is 0.5 percent. LS was estimated as 0.25.

The CP cover and practice factor is a function of the cover type. The following estimates were obtained from Table IV.3-1:

1) Worst case-bare material: 1.00
2) Sparse grass cover: 0.10
3) Good grass cover: 0.02
4) Good grass cover and trees: 0.005

Sheet erosion release rates over a 1000 year period were estimated as:

1) Tailings Cover:

   a) bare material: 2.0 metres
   b) sparse grass: 0.2 metres
   c) good grass: insignificant

2) Till Cover:

   a) bare material: 0.6 metres
   b) sparse grass: 0.1 metres
   c) good grass: insignificant

3) Waste rock:

   a) bare material: 0.1 metres
   b) sparse grass: insignificant

It is probable that a sparse to good grass cover will be established on the tailings and the gross sheet erosion cover loss will be 0.1 to 0.2 metres.

With a till cover it is anticipated that a good grass cover will be established within a few years and that in the long term trees will grow. The expected release rate from sheet erosion will therefore probably be less than 0.1 metres.

However, in addition to the average annual release rates it is anticipated that there will be some additional sheet and rill erosion associated with severe storms. The MUSLE procedure was used to estimate sediment yields associated with the 10, 25, 50, and 100 year 24 hour events and the PMP event. It was assumed that events smaller than the 10 year event were accounted for by the USLE procedure.

The WASHED computer model was used to make the MUSLE estimates. The basic input data set for Elliot Lake is presented in Appendix V.1.1. and a typical output file is presented in Appendix V.1.2. Erosion estimates are summarized in Table V.1-1. These estimates were then adjusted to account for K and CP factors of a particular cover option.

Based on the estimates presented in Table V.1-1 the following severe storm estimates were obtained:

TABLE V.1-1

SEVERE EVENT SEDIMENT YIELDS FROM COVERS

EVENT	ONTARIO			SASKATCHEWAN WET			SASKATCHEWAN DRY		
YRS	RAINFALL (mm)	FOREST (tonnes)	COVER (tonnes)	RAINFALL (mm)	FOREST (tonnes)	COVER (tonnes)	RAINFALL (mm)	FOREST (tonnes)	COVER (tonnes)
2	55	1800	800	35	240	70	35	50	40
5	75	3400	1600	50	660	200	50	220	140
10	85	4400	2000	65	1240	390	65	480	260
25	100	6000	2800	75	1700	530	75	700	350
50	115	7700	3600	85	2200	680	85	950	450
100	125	9000	4200	100	3000	920	100	1400	610
PMP	300	34200	15800	300	17000	5100	300	9000	3400
PARA-METER	UNITS			UNITS			UNITS		
AREA	ha	200	160	ha	270	40	ha	80	45
CP		1.0	1.0		1.0	1.0		1.0	1.0
K		0.25	0.25		0.15	0.15		0.15	0.15

1) Tailings Cover:

a)	bare material:	0.3 metres
b)	sparse grass:	0.03 metres
c)	good grass:	insignificant

2) Till Cover:

a)	bare material:	0.1 metres
b)	sparse grass:	0.01 metres
c)	good grass:	insignificant

3) Waste Rock:

a)	bare material:	insignificant

Therefore, the total sheet and rill erosion release rate will be about 0.2 metres for a grassed tailings cover and 0.1 metres for a grassed till cover.

The depth of incision due to gully erosion was estimated by the procedure of Falk et al. (1985). The procedure is defined by Equation IV.3.8 through Equation IV.3.13.

Cover material physical characteristics were determined as follows from the available laboratory grading analysis:

1) Fine tailings:

a)	D_{50}:	0.02 mm
b)	C_u:	6.0

2) Coarse tailings:

a)	D_{50}:	0.20 mm
b)	C_u:	6.3

3) Till material:

a)	D_{50}:	0.20 mm
b)	C_u:	50

4) Waste rock:

a)	D_{50}:	20 mm
b)	C_u:	5

The tributary drainage area was calculated from Equation IV.3.9 as 2260 m^2 (24,300 ft^2). Based on the available rainfall information it was estimated that about 10 events with more than 13 mm (0.5 inches) of rainfall would occur each year.

The depth of incision for the waste rock was estimated to be about 1.0 metres after a period of 200 years.

The depth of incision for both the tailings and till material was estimated to be about 4 metres after a period of 200 years. This very high rate is primarily due to the very large contributing drainage area and to the high number of large rainfall events each year. To reduce these release rates to acceptable levels it would be necessary to install:

1) an upstream diversion system
2) terraces
3) drainage control on the cover

V.1.3.2 Wet Tailings Site, Saskatchewan

Details on the Saskatchewan Wet Tailings Site have been presented in Chapter II.3.0 of Technical Memorandum II. A plan of the site is presented in Figure II.3.1-1.

In order to prevent runoff discharging onto the impoundment diversion ditches are located along the north and south sides of the impoundment. It is proposed that the cover will be graded at a 2 percent slope towards the diversion ditch on the south side of the impoundment (see Figure II.3.4-7). The following cover materials will be considered:

1) Waste rock

2) Sandy till

Average annual sheet and rill erosion was estimated by the USLE. The rainfall erosion factor, R, was estimated by using equation IV.3.5. From the available information it was established that the 2 year, 6 hour rainfall is about 21.0 mm and the average annual rainfall during the period from December to May was estimated as 1000 mm. The rainfall factor was calculated to be about 30.

The soil erodibility factor, K, for the different cover materials was determined by using the nomographs presented as Figures IV.3-2 and IV.3-3. Basic input parameters for the tailings and till materials were:

1) Waste Rock:

a)	% silt + % fine sand:	10	percent
b)	% sand:	30	percent
c)	soil structure:	4	
d)	permeability:	2	
e)	organic matter %:	0 to 2	percent

2) Sandy Till:

a)	% silt + % fine sand:	30	percent
b)	% sand:	40	percent
c)	soil structure:	3	
d)	permeability:	2 or 3	
e)	organic matter %:	0 to 3	percent

The K factor for the waste rock and sandy till materials were estimated as 0.05 and 0.15 respectively.

The LS factor was calculated from Equation IV.3.6. The average length was estimated as about 600 m (2000 ft) and the average cover slope is 2 percent. LS was estimated as 0.5.

The CP cover and practice factor is a function of the cover type. The following estimates were obtained from Table IV.3-1:

1) Worst case-bare material: 1.00
2) Sparse grass cover: 0.10
3) Good grass cover: 0.02
4) Good grass cover and trees: 0.005

Based on the USLE sheet erosion release rates over a 1000 year period were estimated as:

1) Waste Rock Cover:

   a) bare material: 0.1 metres
   b) sparse grass: insignificant

2) Sandy Till Cover:

   a) bare material: 0.3 metres
   b) sparse grass: 0.03 metres
   c) good grass: insignificant

3) Silty Till Cover:

   a) bare material: 0.6 metres
   b) sparse grass: 0.06 metres
   c) good grass: insignificant

It is probable that sparse grass cover will be established on the waste rock and the gross sheet erosion cover loss will be insignificant.

With a till cover it is anticipated that a good grass cover will be established within a few years and that in the long term trees will grow. The expected release rate from sheet erosion will therefore also be insignificant.

The WASHED computer model was used to make the MUSLE estimates. Erosion estimates are summarized in Table V.1-1. These estimates were then adjusted to account for K and CP factors of a particular cover option.

Based on the estimates presented in Table V.1-1 the following severe storm estimates were obtained:

1) Waste Rock Cover:

   a) bare material: 0.04 metres
   b) sparse grass: insignificant

2) Sandy Till Cover:

a)	bare material:	0.1 metres
b)	sparse grass:	0.01 metres
c)	good grass:	insignificant

3) Silty Till Cover:

a)	bare material:	0.2 metres
b)	sparse grass:	0.02 metres
c)	good grass:	insignificant

Total sheet and rill erosion release rate for the waste rock cover will probably be insignificant and less than 0.1 metres for the till covers.

The depth of incision due to gully erosion was estimated by the procedure of Falk et al. (1985). The procedure is defined by Equation IV.3.8 through Equation IV.3.13.

Cover material physical characteristics were determined as follows from the available laboratory grading analysis:

1) Waste Rock:

a)	D_{50}:	5.0 mm
b)	C_u:	10.0

2) Sandy Till:

a)	D_{50}:	0.5 mm
b)	C_u:	50.0

3) Silty Till:

a)	D_{50}:	0.3 mm
b)	C_u:	20

The tributary drainage area was calculated from Equation IV.3.9 as 250 m^2 (2670 ft^2). Based on the available rainfall information it was estimated that about 5 events with more than 13 mm (0.5 inches) of rainfall would occur each year.

After 200 years the depth of incision for the sandy and silty till materials was estimated to be about 4 and 6 metres respectively. This very high rate is primarily due to the very large contributing drainage area. An estimate of gully incision with a waste rock cover could not be made as the parameters fell outside of the range for the procedure. However, based on the original work of Falk et al. (1985) it was possible to make an estimate based on the following equation and Figure V.1-1:

$$GF = \frac{[A\ P\ S_i]}{[1 + D_{50}]} \qquad (1.1)$$

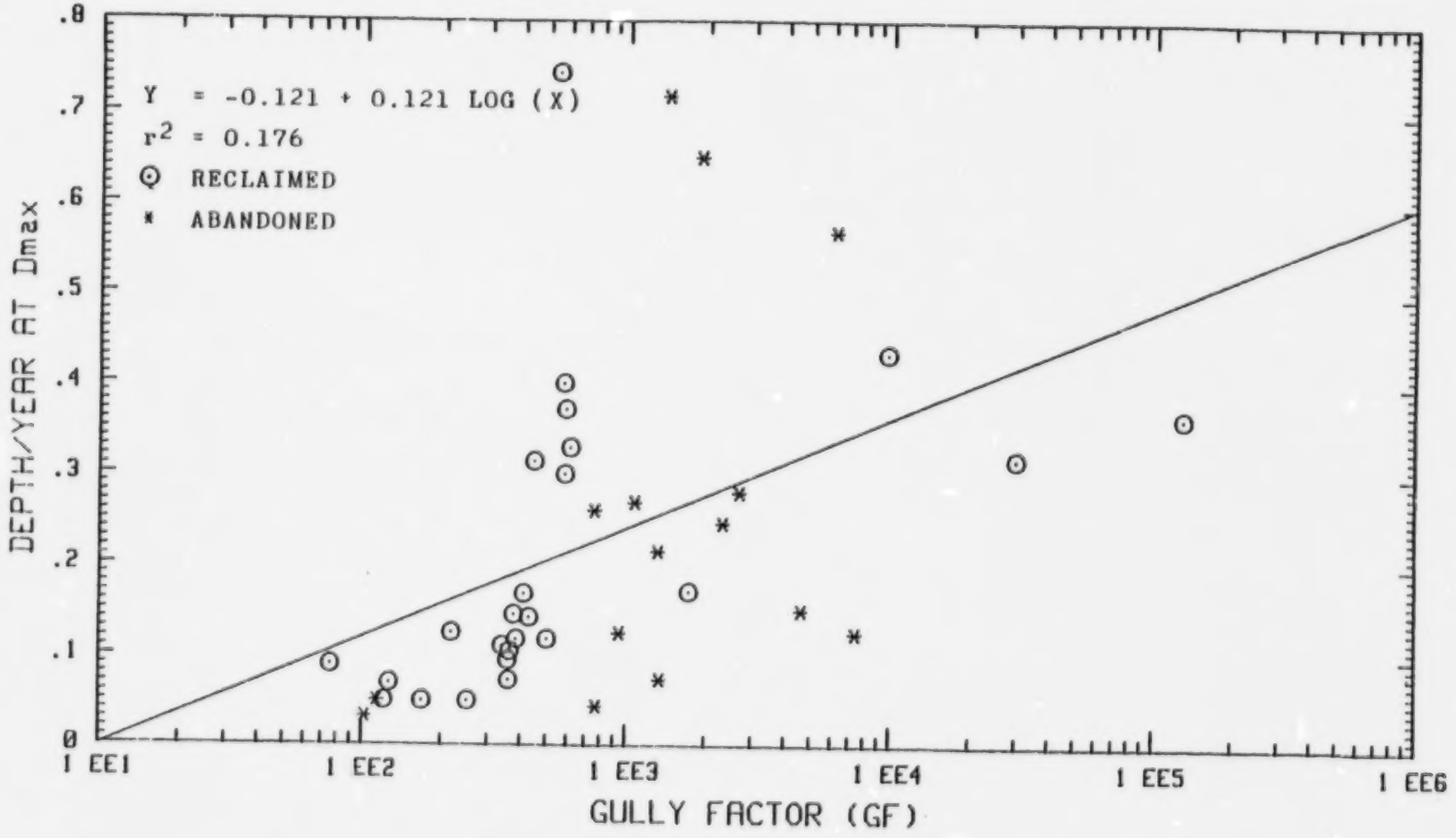


FIGURE V.1-1

GULLY FACTOR VERSUS AVERAGE RATE OF INCISION FOR ALL GULLIES INVESTIGATED

From Figure V.1-1 it was established that the depth of incision would only be slightly less than for the other two materials.

To reduce these release rates to acceptable levels it would be necessary to:

1) reduce the cover slope
2) install terraces
3) install drainage control on the cover

V.1.3.3 Semi-dry Tailings Site, Saskatchewan

Details on the Saskatchewan Semi-dry Tailings Site have been presented in Chapter II.4.0 of Technical Memorandum II. A plan of the site is presented in Figure II.4.1-1.

The impoundment is contained in a horseshoe shaped dyke. The northwestern boundary of the impoundment is a topographic rise. An area of about 80 ha drains towards the impoundment. Storm runoff from this area drains around the southwestern perimeter of the impoundment.

It is proposed to grade the cover at a 2% slope as shown in Figure II.4.4-5. To demonstrate the effect of a variety of cover slopes the following analyses were made for a 1% slope (intermediate between the 2% slope for the Saskatchewan Wet Tailings site and the 0.5% slope for the Elliot Lake site). The following cover alternatives will be considered:

1) Tailings

2) Sandy till

3) Waste rock

Average annual sheet and rill erosion was estimated by the USLE. The rainfall erosion factor, R, was estimated by using equation IV.3.5. From the available information it was established that the 2 year, 6 hour rainfall is about 21.0 mm and the average annual rainfall during the period from December to May was estimated as 1000 mm. The rainfall factor was calculated to be about 30.

The soil erodibility factor, K, for the different cover materials was determined by using the nomographs presented as Figures IV.3-2 and IV.3-3. Basic input parameters for the tailings and till materials were:

1) Tailings:

a)	% silt + % fine sand:	75	percent
b)	% sand:	25	percent
c)	soil structure:	1	
d)	permeability:	4	
e)	organic matter %:	0 to 2	percent

2) Sandy Till:

a)	% silt + % fine sand:	15	percent
b)	% sand:	60	percent
c)	soil structure:	3	
d)	permeability:	3	
e)	organic matter %:	0 to 3	percent

3) Waste Rock

a)	% silt + % fine sand:	10	percent
b)	% sand:	30	percent
c)	soil structure:	4	
d)	permeability:	2	
e)	organic matter %:	0 to 2	percent

The K factor for the tailings, sandy till, and waste rock materials were estimated as 0.60, 0.15, and 0.05 respectively.

The LS factor was calculated from Equation IV.3.6. The average length was estimated as about 400 m (1300 ft.) and the average cover slope is 1%. LS was estimated as 0.3.

The CP cover and practice factor is a function of the cover type. The following estimates were obtained from Table IV.3-1:

1)	Worst case-bare material:	1.00
2)	Sparse grass cover:	0.10
3)	Good grass cover:	0.02
4)	Good grass cover and trees:	0.005

Based on the USLE, sheet erosion release rates over a 1000 year period were estimated as:

1) Tailings:

a)	bare material:	0.8 metres
b)	sparse grass:	0.08 metres
c)	good grass:	insignificant

2) Sandy Till Cover:

a)	bare material:	0.2 metres
b)	sparse grass:	0.01 metres
c)	good grass:	insignificant

3) Waste Rock Cover:

a)	bare material:	0.06 metres
b)	sparse grass:	insignificant

It is anticipated that at best only sparse to good grass could be established on the tailings materials and sheet erosion will be 0.2 to 0.8 metres.

With a till cover it is anticipated that a good grass cover will be established within a few years and that in the long term trees will grow. The expected release rate from sheet erosion will therefore be insignificant.

It is probable that sparse grass cover will be established on the waste rock and the gross sheet erosion cover loss will be insignificant.

The WASHED computer model was used to make the MUSLE estimates for severe storm events. Erosion estimates are summarized in Table V.1-1. These estimates were then adjusted to account for K and CP factors of a particular cover option.

Based on the estimates presented in Table V.1-1 the following severe storm estimates were obtained:

1) Tailings Cover:

   a) bare material: 0.5 metres
   b) sparse grass: 0.05 metres
   c) good grass: insignificant

2) Sandy Till Cover:

   a) bare material: 0.1 metres
   b) sparse grass: 0.01 metres
   c) good grass: insignificant

3) Waste Rock Cover:

   a) bare material: 0.03 metres
   b) sparse grass: insignificant

Total sheet and rill erosion release rate for a bare to sparsely grassed tailings cover will probably be 0.1 to 0.5 metres. Losses from a grassed till or waste rock cover will be insignificant.

The depth of incision due to gully erosion was estimated by the procedure of Falk et al. (1985). The procedure is defined by Equation IV.3.8 through Equation IV.3.13.

Cover material physical characteristics were determined as follows from the available laboratory grading analysis:

1) Tailings:

   a) D_{50}: 0.04 mm
   b) C_u: 3.0

2) Silty Till:

   a) D_{50}: 0.3 mm
   b) C_u: 6.3

3) Waste Rock:

a) D_{50}: 5.0 mm
b) C_u: 10.0

The tributary drainage area was calculated from Equation IV.3.9 as 140 m^2 (1490 ft^2). Based on the available rainfall information it was estimated that about 5 events with more than 13 mm (0.5 inches) of rainfall would occur each year.

Estimates of gully incision could not be made as the parameters fell outside of the range for the procedure. However, based on the original work of Falk et al. (1985) it was possible to make an estimate based on the following equation and Figure V.1-1:

$$GF = \frac{[A\ P\ S_i]}{[1 + D_{50}]}$$

From Figure V.1-1 it was established that the rate of incision would be 0.01 to 0.03 metres per year for the three alternative cover materials.

To reduce these release rates to acceptable levels it would be necessary to:

1) reduce the cover slope
2) install terraces
3) install drainage control on the cover

V.1.4 WIND EROSION

V.1.4.1 Typical Tailings Site, Ontario

Wind erosion was estimated by using the procedure outlined in Chapter IV.3.2 of Technical Memorandum IV. Soil erodibility factor, I, for the different cover materials was estimated as follows:

1) Fine tailings (5% non-erodible): 180 tons/acre/year
2) Coarse tailings (15% non-erodible): 117 tons/acre/year
3) Till material (20% non-erodible): 98 tons/acre/year

Based on the available wind velocity information, map information and discussion with Canadian wind erosion experts it is anticipated that the the climatic factor, C, will vary from 25 to 50 percent.

For a sparse to good grass cover it is anticipated that during a 1000 year period wind erosion from a tailings cover would be 5 to 10 metres and 3 to 6 metres from a till cover. If trees are established these rates would probably reduce to less than 1 metre.

V.1.4.2 Wet Tailings Site, Saskatchewan

Wind erosion was estimated by using the procedure outlined in Chapter IV.3.2 of Technical Memorandum IV. The soil erodibility factor, I, for the different cover materials was estimated as follows:

1)	Waste Rock	(80% non-erodible):	2 tons/acre/year
2)	Sandy Till	(40% non-erodible):	56 tons/acre/year
3)	Silty Till	(20% non-erodible):	98 tons/acre/year

Based on the available wind velocity information, map information and discussions with Canadian wind erosion experts it is anticipated the the climatic factor, C, will vary from 25 to 150 percent depending on the cover material type and vegetative cover.

For the waste rock cover, wind erosion will be insignificant. For a good grass cover it is anticipated that during a 1000 year period wind erosion from a sandy till cover would be 2 to 8 metres and 1 to 4 metres from a silty till cover. If trees are established these rates would probably reduce to a small percentage of the above figures.

V.1.4.3 Semi-dry Tailings Site, Saskatchewan

Wind erosion was estimated by using the procedure outlined in Chapter IV.3.2 of Technical Memorandum IV. The soil erodibility factor, I, for the different cover materials were estimated as follows:

1)	Tailings	(0% non-erodible):	310 tons/acre/year
2)	Sandy Till	(30% non-erodible):	74 tons/acre/year
3)	Waste Rock	(80% non-erodible):	2 tons/acre/year

For the waste rock cover wind erosion will be insignificant. For a good grass cover it is anticipated that during a 1000 year period wind erosion from a sandy till cover would be 3 to 10 metres and 10 to 30 metres from a tailings cover. If trees are established these rates would probably reduce to a small percentage of the above figures.

V.1.5 INFILTRATION

The methodology for infiltration estimation has been presented in section III.6 of Technical Memorandum III. The results of modelling can vary tremendously depending on local climatic conditions and the precise details of cover slope and surface texture, cover material and vegetation cover. Some of these parameters (slope, vegetation cover and surface texture) are expected to change with time as the tailings consolidates and the effects of vegetation and surface erosion develop. Detailed analyses for the various impoundments and cover types could not be completed within the scope of this study.

In section III.5.1 the results of the application of some of the modelling techniques to a tailings impoundment in climatic conditions fairly similar to those at Elliot Lake (performed for a massive sulphide tailings impoundment in northern Wisconsin) are presented. The types of cover materials were similar to those proposed in this study. The results are

presented in Table III.5-1. These evaluations may be taken as indicative of similar cover performance at Elliot Lake. Infiltration rates to the tailings below the cover layers (all of which included a 15 cm bentonite modified soil seal layer) ranged from 15 mm in a dry year for covers which included a drainage layer above the seal layer to 112 mm in a very wet year for the cover without a drainage layer. Use of a soil seal layer without a drainage layer above it resulted in saturation of the cover to the surface for a 4 month period which would be detrimental to vegetation. Inclusion of the drainage layer, above the seal layer, eliminated this problem but dry soil moisture conditions resulted for two and five months for normal and dry years respectively.

An evaluation of Saskatchewan experience has been made in section IV.3.6. The recharge rates are subject to the broad assumptions discussed in IV.3.6. They show the trend in recharge may be in error in absolute terms by 50% or more. The mean annual precipitation at the wet tailings (W.T.) site is 400 mm and at the semi-dry (S.D.) site 415 mm. As there is no appreciable difference in precipitation, the sites are not differentiated in this section.

The cover alternatives considered are:

- no cover
- thin soil
- thick rock
- thick cover (soil, rock, soil-bentonite)
- thick cover (rock, soil, soil-bentonite)

For no cover, the ratio of infiltration will be governed by the tailings properties and is estimated as 20% of precipitation (80 mm per year) for vegetated and non-vegetated surfaces. A thick soil cover would be slightly coarser in texture than the tailings and would have no appreciable affect upon infiltration. A thin rock cover would have markedly higher permeability. The net infiltration rate would still be controlled by the tailings properties, however, the rock will tend to provide a "sink", retarding runoff, and detaining surface water in contact with the tailings. It is conceivable that the water will be in contact with the soil for twice as long and a doubling of infiltration rate is appropriate (160 mm per year).

For both thick covers, the soil-bentonite liner will limit infiltration to about 30 mm per year. Infiltration in excess of 30 mm will run off through the rock layer, whether it be on the surface or directly over the liner. The hydraulic capacity of the rock is sufficient to conduct runoff to the edge of the tailings at the proposed tailings slopes of 2%.

Forest vegetation will reduce the amount of infiltration. Based on Saskatchewan Highways and Transportation experience, an infiltration reduction of 50% is appropriate. For thin covers, therefore, forested infiltration would be approximately 40 mm per year. A smaller reduction would apply to the thick cover conditions.

V.1.6 PHYSICAL INSTABILITY

V.1.6.1 Differential Settlement

V.1.6.1.1 Saskatchewan Sites

Estimates have been made of the anticipated maximum settlements in the fine and coarse grained tailings at the Saskatchewan tailings sites. These estimates are given in sections II.3.5 (Table II.3.5-1) and II.4.5 for the wet tailings and semi-dry tailings sites respectively. Total settlements of 2 to 3 m are anticipated. Estimates of the time rate of settlement indicated that 90% consolidation would occur in 13 and 30 years for the two sites respectively. These estimates do not allow for consolidation that may follow thawing of zones of tailings, up to 3 m or more in thickness, which may have become frozen on placement. Differential settlements of at least 50% of the total settlement can be anticipated.

If this differential settlement occurred within a distance of 50 m the slope change would be in the range of 2% to 3%. This is large enough to cause ponding on covers with initial slopes of less than 2 to 3%.

Where there is a sharp transition in material types or frozen/unfrozen zones, differential settlement could take place over shorter distances and local cracking of brittle cap layers is anticipated.

V.1.6.1.2 Typical Tailings Site, Ontario

No site specific estimates have been made of differential settlements of covers on the Elliot Lake site. It is anticipated that an evaluation would result in essentially the same results as for the Saskatchewan wet tailings site.

V.1.6.2 Shrinkage

V.1.6.2.1 Saskatchewan Sites

(a) Thin Covers

Thin cover layers will be subjected to large seasonal moisture variations, cracking of this layer is anticipated.

(b) Thick Cover Layers

The thick common fill cover layer will be subject to large moisture variations in the upper zones. Variations will reduce with depth. With the relatively low linear shrinkage of the tills and sands, cracking (due to shrinkage) should not occur in the lower portions of the layer.

For those covers where a permeable rock waste or sand zone overlies the bentonite modified low permeability layer, the moisture in the bentonite modified layer will be maintained at a high value. No cracking, due to shrinkage as a result of desiccation, is anticipated. Shrinkage as a result of bentonite modification by ion exchange with the tailings

solutions is considered unlikely, but must be evaluated. This aspect has been further discussed in IV.5.1.

V.1.6.2.2 Typical Tailings Site, Ontario

The higher precipitation at the Ontario site will result in lower moisture fluctuations. However, the conclusions reached for the Saskatchewan sites apply also to the Ontario site.

V.1.6.3 Frost Heave

Frost action at the Ontario site is considerably less than at the Saskatchewan sites. Permafrost has not been observed and is not considered a cause of long term instability. Seasonal frost will have some effect as discussed for the Saskatchewan sites.

The frost and frost heave conditions were evaluated at two generic sites (W.T., S.D.) in Saskatchewan. Various cover schemes including thin cover, thick cover, and no cover, in vegetated and unvegetated states, were considered. Items considered include:

a) potential for permafrost aggradation
b) potential frost "pumping" of tailings fluid
c) potential for surface release of pumped fluid
d) influence of frost action on cover design and performance

V.1.6.3.1 Wet Tailings Site, Saskatchewan

The environmental, tailings and cover characteristics are summarized in Table IV.3-7 which is a sample output from the thermal-frost heave model. The analytical method is described in Section IV.3.5.3.

The ratio of the depth of thaw to depth of frost is summarized in Table V.1-2 for various cover conditions. In most cases, the depth of frost is greater than the depth of thaw which suggests the ground thermal balance favours permafrost aggradation.

In the natural soils with a low moisture content and extensive vegetative cover, the thaw depth is greater and permafrost aggradation is not favoured. The tendency for frost aggradation is greater when the high moisture content soils are closer to the surface. Thus, the tendency decreases with increasing cover thickness.

Should the thermal model be incorrect, and permafrost aggradation not occur, then fluid may be transported to the surface. The amount of pore fluid segregated by the frost heave process is illustrated in Figure IV.3-13. The amount of heave decreases markedly with increasing depth to the water table (increased suction at the freezing front) and increasing cover thickness.

The water released during thaw will run off or evaporate. The net potential evaporation, precipitation and released water during thaw is shown in Table V.1-3 for vegetated cover thicknesses of 0.6, 2 and 3 m, and a water table depth of 1 m. For unzoned covers, the released fluid must

TABLE V.1-2

PREDICTED FREEZING-THAWING DEPTH,
WET TAILINGS SITE, SASKATCHEWAN

CASE	FREEZING DEPTH (m)	THAWING DEPTH (m)	RATIO
No cover, bare	2.2	1.1	.50
No cover, vegetated	1.6	1.15	.72
0.6 m cover, vegetated	1.9	1.6	.84
2 m cover, vegetated	2.6	2.7	1.04
3 m cover, vegetated	3.1	3.5	1.12

TABLE V.1-3

POTENTIAL FLUID RELEASE FROM FROST "PUMPING",
WET TAILINGS SITE, SASKATCHEWAN

	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
Mean Temperature °C	4.7	11.8	15.5	13.8	6.7	0.61
Potential Evapotranspiration (mm)	4.9	105	127	103	48	0
Precipitation (mm)	27	51	64	56	51	33
Net potential evaporation (mm)	22	54	63	47	-3	-33
Fluid Released by thaw:						
No cover, bare (mm)	63	37	28	24	20	18
No cover, vegetated (mm)	45	27	22	18	15	14
0.6 m cover, vegetated (mm)	32	26	20	16	15	13
2 m cover, vegetated (mm)	0	0	11	13	11	10
3 m cover, vegetated (mm)	0	0	0	0	0	8

NOTE: Water table at 1 m depth

move to the surface where it evaporates or runs off. For a zoned cover, the fluid can be intercepted by the granular cover zone and drain (no evaporation).

During the months of May, September and October, the amount of fluid released is greater than the net potential evapotranspiration and runoff of the released fluid can be expected. For the no cover, bare case, the amount is approximately 75 mm per year. The released fluid decreases to approximately 50 mm when vegetated and drops to almost nil with a 3 m cover. For thicker covers with a basal drainage layer, the fluid would be released directly to the drainage zone without evaporation loss.

Frost action on the cover can initiate freeze cracking of infiltration barriers. The effects of freeze cracking increase with the plasticity of the soil. No naturally occurring materials with sufficient plasticity for concern are available. However, bentonite additives for infiltration control must be used with caution in a freeze-thaw environment. Control over the degree of disturbance is possible by placing the infiltration barrier at the lower part of the cover where the temperature differences are moderated.

It is concluded that in the absence of vegetation cover there will be a high probability of frost aggradation and frost heave.

Both vegetation cover and thin cover significantly reduce the potential for frost heave but it seems probable that frost heave will occur, particularly during periods when climatic conditions favour frost aggradation. Such covers are unlikely to be stable in the long term.

With cover depth of between 2 m and 3 m depth there is a low potential for frost aggradation and frost heave in the tailings. Such covers may be stable in the long term.

Frost pumping of tailings water is anticipated with all homogeneous covers with a depth of less than 3 m. Incorporation of a high permeability drainage layer in a thick (3 m) cover should prevent such pumping to the surface but may result in lateral drainage of tailings water from this layer.

V.1.6.3.2 Semi-Dry Tailings Site, Saskatchewan

The environmental, tailings and cover characteristics are summarized in Table IV.3-7 which is a sample output from the thermal-frost heave model. The tailings moisture content and depth to the water table differ from that for the wet tailings site. Also, thermal conditions are slightly warmer. The ratio of the depth of the thaw to depth of frost is summarized in Table V.1-4 for various cover conditions. For 0 to 2 m of cover, the thaw depth is less which shows permafrost conditions are favoured. For a 3 m cover, thawing conditions are favoured.

The predicted amount of ice segregation and potential net evapotranspiration is presented in Table V.1-5. The water released is much less than the W.T. site because of the increased depth to the water table. For the no cover case, fluid in excess of potential evapotranspiration is

TABLE V.1-4

PREDICTED FREEZING-THAWING DEPTH,
SEMI-DRY TAILINGS SITE, SASKATCHEWAN

CASE	FREEZING DEPTH (m)	THAWING DEPTH (m)	RATIO
No cover, bare	2.0	.85	.42
No cover, vegetated	1.48	.85	.57
0.6 m cover, vegetated	1.75	1.3	.74
2 m cover, vegetated	2.5	2.4	.96
3 m cover, vegetated	3.1	3.2	1.03

TABLE V.1-5

FLUID RELEASE BY FROST "PUMPING",
SEMI-DRY TAILINGS SITE, SASKATCHEWAN

	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
Mean Temperature °C	6.1	12.9	15.6	14.4	7.9	1.6
Potential Evapotranspiration (mm)	57	109	125	104	53	12
Precipitation (mm)	26	51	79	61	57	30
Net potential evaporation (mm)	31	58	46	43	-4	-18
Fluid Released by thaw:						
No cover, bare (mm)	28	17	15	13	12	11
No cover, vegetated (mm)	20	12	10	8	8	8
0.6 m cover, vegetated (mm)	14	12	10	9	8	8
2 m cover, vegetated (mm)	0	0	6	8	8	8
3 m cover, vegetated (mm)	0	0	0	0	0	4

NOTE: Water table at 3 m depth

only released during late fall and is limited to about 20 mm. All other cases have a lower release.

Frost action on the cover is similar to the W.T. Site.

V.2.0 EVALUATION OF EMBANKMENT STABILITY

V.2.1 WATER EROSION

V.2.1.1 Typical Tailings Site, Ontario

Details on the Ontario tailings impoundment have been presented in Section II.2 of Technical Memorandum II. Typical embankment cross-sections are presented in Figure II.2.4-1.

Dam A, at its maximum height is 20 m and has a crest length of 300 m. As shown, the downstream slope is 2:1 and is covered with two erosion control layers.

Dam B has a maximum height of 15 m and has a crest length of 230 m. The downstream slope is also 2:1 and is constructed from waste rock.

Average annual sheet and rill erosion was estimated by the USLE. Estimates of USLE parameters for the downstream embankment materials are:

1)	Rainfall Erosion Factor R:	60
2)	Soil Erodibility Factor K:	0.05
3)	Length Slope Factor LS:	
	Dam A:	15
	Dam B:	12
4)	Cover Practice Factor:	
	Bare Soil:	1.0
	Sparse Grass:	0.1
	Good Grass:	0.02
	Good Grass with Trees:	0.01

Cover losses on both dams could range from 0.3 to 15 metres depending on the cover type. If trees are established, losses would be less than 0.2 metres. It is anticipated that a sparse to good grass cover will be established and losses will be 0.5 to 2.0 metres.

Severe storm estimates were made with the WASHED computer model. The basic input data set for the Ontario site is presented in Appendix V.2.1. and a typical output file is presented in Appendix V.2.2. Erosion estimates are summarized in Table V.2.1. These estimates were then adjusted to account for K and CP factors of a particular cover option.

Based on the estimates presented in Table V.2-1 the following estimates of severe storm erosion were obtained:

1) Dam A:

a)	bare material:	1.50	metres
b)	sparse grass:	0.15	metres
c)	good grass:	0.03	metres

TABLE V.2-1

SEVERE EVENT SEDIMENT YIELDS FROM EMBANKMENTS

EVENT	ONTARIO SITE			SASKATCHEWAN WET		SASKATCHEWAN DRY	
(YRS)	RAINFALL (mm)	DAM A (tonnes)	DAM B (tonnes)	RAINFALL (mm)	EMBANKMENT (tonnes)	RAINFALL (mm)	EMBANKMENT (tonnes)
2	55	170	6	35	5	35	110
5	75	330	13	50	70	50	300
10	85	420	17	65	160	65	540
25	100	560	25	75	240	75	720
50	115	710	34	85	330	85	920
100	125	820	40	100	490	100	1230
PMP	300	2920	180	300	3460	300	6400
PARA-METER	UNITS			UNITS		UNITS	
AREA	ha	0.50	0.5	ha	1.0	ha	2.0
CP		1.0	1.0		1.0		1.0
K		0.25	0.05		0.25		.15

2) Dam B:

a)	bare material:	0.60 metres
b)	sparse grass:	0.06 metres
c)	good grass:	insignificant

Therefore, the total sheet and rill erosion release rates on each dam will be about 0.2 metres for a sparse to good grass cover.

The depth of incision due to gully erosion was estimated by the procedure of Falk et al. (1985). Input parameters for the procedure were estimated as:

1) Dam A:

D_{50}:	10.0 mm
Uniformity coefficient:	40
Tributary area:	90 m^2 (990 ft^2)

2) Dam B:

D_{50}:	5.0 mm
Uniformity coefficient:	10
Tributary area:	90 m^2 (990 ft^2)

The stable side slope angle for Dam A is 2:1 and it is anticipated that no gully erosion will occur on the downstream face. The depth of incisions for Dam B will be about 2.5 metres after 200 years.

V.2.1.2 Wet Tailings Site, Saskatchewan

A typical cross-section of the embankment is presented in Figures II.3.4-1 and II.3.4-8. The downstream portion of the embankment is constructed from compacted silty till and has a side slope angle of 2:1 prior to flattening for decommissioning. The following analysis is made assuming slopes are not flattened on decommissioning.

Average annual sheet and rill erosion was estimated by the USLE. Estimates of USLE parameters for the downstream embankment materials are:

1)	Rainfall Erosion Factor R:	30
2)	Soil Erodibility Factor K:	0.15
3)	Length Slope Factor LS:	16
4)	Cover Practice Factor:	
	Bare Soil:	1.0
	Sparse Grass:	0.1
	Good Grass:	0.02
	Good Grass with Trees:	0.01

Cover losses will probably range from 0.03 to 1.0 metres depending on the cover type. If trees are established losses would be less than 0.2 metres. It is anticipated that a sparse to good grass cover will be established and losses will be less than 0.02 metres.

Severe storm estimates were made with the WASHED computer model. Erosion estimates are summarized in Table V.2-1. These estimates were then adjusted to account for K and CP factors of a particular cover option.

Based on the estimates presented in Table V.2-1 severe storm losses were estimated to be 0.03 to 1.6 metres. With a sparse to good grass cover, losses will be less than 0.2 metres and the total water erosion loss 0.1 to 0.3 metres.

The depth of incision due to gully erosion was estimated by the procedure of Falk et al. (1985). Input parameters for the procedure were estimated as:

1) D_{50}: 0.5 mm
2) Uniformity coefficient: 50
3) Tributary area: 190 m^2 (2000 ft^2)

The depth of incision after 200 years was estimated to be 1.5 metres.

Flattening the slope and placing of riprap as proposed for the reclamation plan would considerably reduce erosion potentials.

V.2.1.3 Semi-dry Tailings Site, Saskatchewan

A typical cross-section of the embankment is presented in Figure II.4.4-6 and II.4.1-2. The downstream portion is constructed from compacted fill and has a side slope angle of 2:1.

Average annual sheet and rill erosion was estimated by the USLE. Estimates of USLE parameters for the downstream embankment materials are:

1) Rainfall Erosion Factor R: 30
2) Soil Erodibility Factor K: 0.15
3) Length Slope Factor LS: 12 to 16
4) Cover Practice Factor:
   - Bare Soil: 1.0
   - Sparse Grass: 0.1
   - Good Grass: 0.02
   - Good Grass with Trees: 0.01

Cover losses will probably range from 0.2 to 10.0 metres depending on the cover type. If trees are established, losses would be less than 0.1 metres. It is anticipated that a sparse to good grass cover will be established and losses will be less than 1.0 metres.

Severe storm estimates were made with the WASHED computer model. Erosion estimates are summarized in Table V.2-1. These estimates were then adjusted to account for K and CP factors of a particular cover option.

Based on the estimates presented in Table V.2-1 severe storm losses were estimated (theoretical calculations) to be 0.8 to 40.0 metres. With a sparse to good grass cover losses will be less than 4.0 metres and the total water erosion loss 0.2 to 5.0 metres.

The depth of incision due to gully erosion was estimated by the procedure of Falk et al. (1985). Input parameters for the procedure were estimated as:

1) D_{50}: 0.3 mm
2) Uniformity coefficient: 6.3
3) Tributary area: 60 m^2 (600 ft^2)

The depth of incision after 200 years was estimated to be about 15 metres.

From the above evaluation of erosion potential of the embankments for all sites it is apparent that gully erosion is the mechanism most likely to result in severe embankment erosion and failure. This mechanism can cause substantial depths of erosion which may steepen embankment slopes, causing local slumping.

The gullying estimates are based on local drainage on the embankment. If the tailings cover surface contributes drainage over the embankment then the rates and depths of gully formation can be greatly increased.

V.2.2 WIND EROSION

V.2.2.1 Typical Tailings Site, Ontario

Wind erosion was estimated by the same procedure used for the cover materials. The following estimates were made for the wind erosion equation parameters:

1) Soil Erodibility factor I:
   Dam A (80% non-erodible): 2 tons/acre/year
   Dam B (70% non-erodible): 12 tons/acre/year

2) Wind Climatic Factor C: 25 to 50 percent

3) Adjustment due to slope length: 70 to 80 percent

4) Adjustment due to vegetative residue: 50 to 100 percent

For a sparse to good grass cover it is anticipated that during a 1000 year period wind erosion from Dam A will be less than 0.05 metres. On Dam B wind erosion losses will probably be 0.2 to 0.4 metres.

V.2.2.2 Wet Tailings Site, Saskatchewan

Wind erosion was estimated by the same procedure used for the cover materials. The following estimates were made for the wind erosion equation parameters:

1) Soil Erodibility factor I,
   Sandy Till (40% non-erodible): 56 tons/acre/year

2) Wind Climatic Factor C: 25 to 150 percent

3) Adjustment due to slope length: 70 to 80 percent

4) Adjustment due to vegetative residue: 50 to 100 percent

For a sparse to good grass cover it is anticipated that during a 1000 year period wind erosion losses will be 2 to 6 metres.
metres.

V.2.2.3 Semi-dry Tailings Site, Saskatchewan

The following estimates were made for the wind erosion equation parameters:

1) Soil Erodibility factor I:
Silty Till (30% non-erodible): 74 tons/acre/year

2) Wind Climatic Factor C: 25 to 150 percent

3) Adjustment due to slope length: 70 to 80 percent

4) Adjustment due to vegetative residue: 50 to 100 percent

For a sparse to good grass cover it is anticipated that during a 1000 year period wind erosion losses will be 3 to 12 metres.

Good tree cover is anticipated on these embankments in the long term which will reduce wind erosion losses to a small fraction of those determined above.

V.2.3 POTENTIAL RATES OF BLOCKAGE FOR UNDERDRAINS

Based on the type of calculations, from section IV.4.4, for the quantities of precipitate that can be potentially lost from pore water solution to the underdrainage system, similar calculations can be performed for the specific pore water chemistries of the 3 generic tailings systems; high sulphide, high sulphide/nickel/arsenic, and low sulphide. It should be emphasized that the use of equilibrium models would yield more reliable estimates of the assessment of drain blockage problems, than this type of calculation. If a situation requires detailed evaluation, therefore, the use of such models is suggested.

V.2.3.1 High Sulphide Tailings Type (Ontario Tailings Site)

In the case of the Ontario type of high pyrite tailings, there are two different pore water chemistries, depending on whether oxidation has occurred or not, and hence alternatives for underdrainage blockage potential. Table I.3.A-3 in TMI gives pore water compositions for normal, "neutralized" tailings and oxidized tailings.

In the neutralized case, the analysis indicates that neither calcium nor iron salts are likely to precipitate because:

- o in the case of iron, its actual concentration is not significant (<1 ppm) and any pH change on equilibrating with the atmosphere would cause a lowering of pH and an increase in iron solubility. Hence, precipitation is unlikely; and

- o the combined masses of the cations calcium and ammonium are virtually sufficient to sustain up to 2000 mg/L of sulphate in solution and, hence, gypsum precipitation, if it occurred, would not be large.

The oxidized tailings have a significant potential for iron/iron sulphide precipitation due to the high dissolved concentrations of iron and sulphate combined with pH levels which will not be in equilibrium with the air in or out of the drainage system over most of these ranges. As discussed in section IV.4.4, a small shift in pH value can cause a considerable change in iron solubility.

With iron values between 3,000 mg/L and 15,000 mg/L, (Table I.3.A-3) there is at least the potential for the precipitation of 12,000 mg/L if the pH were to rise from 2 to 6: this appears to accord with the general chemistry of ferric iron solubility, in an oxidizing medium, summarized by Hem, (1970) and other authors. Expressed as $FeSO_4$ this is equivalent to about 26g of precipitate for each litre of water passing through the drain. Using the 0.12 m^3 void space in a unit length of a 1 m x 0.3 m cross section of an underdrain, described in TMIV, then the void space in the drain could be filled within a matter of days with a flow rate through the drain of 1 litre per second. Such calculations assume complete retention of the precipitate in the void space and almost instantaneous reaction.

In practice, the change in pH due to equilibrium with the air will be a slower process, but a pH shift of a unit can result in up to an order of magnitude change in the solubility of iron in some cases. This would still be sufficient to give the potential for drain blockage in a matter of months.

V.2.3.2 Low Sulphide Type, (Saskatchewan Wet Tailings Site)

The potential problems associated with drain blockage in the wet tailings site appear, at first, to be similar to the S.D. site, due to some similarities in the pore water chemistry for the two types of tailings. The described iron levels are low (0.25 mg/L) and hence the mass of iron precipitate generated would be low, even if there were to be precipitation due to either an increasing pH or Eh.

Sulphate values in the W.T. site are about twice the respective value for the S.D. site at over 6000 mg/L. This high level of sulphate is sustained by the elevated magnesium level in pore water at about 950 mg/L. While there is some potential for calcium sulphate precipitation, the magnesium and sodium in the water would tend to keep most of the sulphate in solution and the total potential for sulphate precipitation is reduced. In essence, it is anticipated that the potential rate and quantity of precipitate for W.T. site to be less than the S.D. site.

V.2.3.3 High Nickel/Arsenic Sulphide Type (Saskatchewan, Semi-dry Tailings Site)

In general terms, the potential for drain blockage is low in the S.D. tailings system as compared with the high pyrite, Elliot Lake type of oxidized tailings as pH values are high and the masses of dissolved species in the S.D. pore water are considerably lower for the species liable to give precipitation problems. However, examination of chemical analyses for the tailings effluent discharged to the impoundment from the S.D. mill indicates that, while iron salts precipitation may not be an issue (values for Fe are <0.1 mg/L), there is sufficient sulphate and calcium in solution to make gypsum and/or calcite precipitation a potential problem. (Sulphate and calcium levels from S.D. tailings, Table II.4.3-2, range between 1310-3450 mg/L and 520 - 1050 mg/L respectively. Tailings water tends to be gypsum saturated.).

Reduction of the calcium levels from 1000 mg/L to 600 mg/L could be entirely possible, resulting in the precipitation of 400 mg of calcium per litre of discharge in the drain. As calcium sulphate, this is equivalent to between 1360 mg and 1700 mg depending on the degree of hydration of the calcium sulphate (i.e., $CaSO_4$ through $CaSO_4.2H_2O$. Complete hydration is expected).

Precipitation of 1.7 g of solids for every litre of water passing through a drain could effect blockage relatively rapidly, if all the precipitate were retained in the drain void space, i.e., within months.

V.2.4 FROST HEAVE

The wet tailings site uses a zoned earth fill with a silty till upstream zone and a sandy till downstream zone (see Figure II.3.4-1). The silty till will be the most frost susceptible material. Upon decommissioning, it will be both insulated from freezing and restrained from sliding by the tailings. The downstream slope is 2:1 which is marginally steeper than some natural slopes in the area. The slope will be regraded to flatter slopes upon decommissioning for erosion protection. For this evaluation a 6:1 slope is assumed though steeper slopes may be considered. This will be more than sufficient for protection against frost induced slumping in these materials.

The 6:1 slope will also cover the existing trench drain to a depth of greater than 3 m which is below the seasonal frost depth. As aggrading permafrost is not anticipated in the embankment soil, drain blockage is not anticipated under the embankment.

In the absence of such re-grading both embankment slumping (solifluction) and seasonal blockage of the drains can be anticipated as a result of frost action.

The semi-dry tailings site employs a bentonite modified till cutoff with an upstream zone of sand and a downstream zone of compacted till (see Figure II.4.1-2). Both up and downstream slopes are 2:1. The downstream slope is steeper than natural slopes; however, upon decommissioning, the slopes will

be flattened to 6:1 for erosion protection. This slope will also be stable with respect to frost induced movements.

The bentonite core may be susceptible to frost action, depending upon the bentonite to sand ratio. If small amounts are used, the mixture may be frost susceptible. If larger amounts are used, it will possess a low permeability and reduced frost susceptibility. On the other hand, the larger bentonite content will increase the plasticity and subject the zone to cold temperature cracking. The net result is that an increase in permeability of one or two orders of magnitude in the freezing zone can be expected.

As for the wet tailings site, after regrading, the subdrainage system will be below the anticipated depth of freezing.

V.2.5 PHYSICAL INSTABILITY

All the embankments in the typical generic sites are constructed of primarily granular materials with a low cohesion and a high friction angle. For initial slope stability evaluations they are considered to be of similar shear strength with friction angles of about 38°.

Present stability of impoundment structures can be estimated by considering the slope geometry, unit weight, shear strength parameters and the pore water pressure conditions. Prediction of future stability requires estimation of future changes that may occur to the same factors. These changes were discussed in Technical Memorandum IV.

Changes in the phreatic surface may occur as a result of blockage of drains. In terms of the pore water pressure, three general conditions can occur; dry conditions; normal development of a phreatic surface in the embankment; and, fully saturated conditions. Dry conditions can be evaluated by considering ru = 0.0. The normal development of a phreatic surface in the slope has approximate ru = 0.2, while a fully saturated condition has an approximate ru = 0.4 . The latter case could promote local instability (particularly at the toe of an embankment when underdrains block).

The embankment materials have been weathered for many thousands of years. Seepage through the tailings impoundments is not expected to cause significant changes in these natural materials. In the zone of active freeze/thaw there will be a reduction in soil density. This will result in a small reduction in shear strength. In general, a reduction in the shear strength from approximately 38 degrees to 35 degrees is anticipated for the active zone in the impoundment structures.

Minor changes in the geometry of the slope may occur as a result of solifluction or sheet erosion. More damaging is steepening due to rilling or gullying in the erodible fine grained sands and silty sand till. The effect of steepening of the slopes is evaluated by examining slope angles of 2 horizontal to 1 vertical (2:1) and 6:1. Evaluation of a 6:1 slope is not intended to suggest that this is the extent of slope flattening that is required. It represents the upper limit of slope flattening that would probably be considered, for comparison with the steeper present slopes.

A comparison of Factors of Safety for various pore water pressure conditions, slope angles and shear strengths is given on Table V.2-2. While the drained embankment has a FS greater than 1.5, when a seepage surface develops through the embankment (ru = 0.2), the overall stability of the impoundment structures is marginal, with F = 1.05 to 1.11. If blockage of the drains occurs resulting in a high phreatic surface (ru = 0.4), a failure of the slope would occur. Comparatively, a 6:1 slope offers a considerable margin of safety with a minimum factor of safety of 2.25. A reduction in the shear strength of the slope material will result in a decrease in the slope stability which is proportional to the change in the tangent of the internal angle of friction for the soil.

In summary, the factor of safety of the impoundment structures with a 2:1 slope is adequate if the slopes remain well drained. However, if the drainage system fails and a normal phreatic surface develops, the slope would fail.

Dam A at the Ontario site and both of the Saskatchewan site embankments depend on drainage layers to reduce the level of the phreatic surface. It is considered that there is a moderate to high potential that these drainage systems will fail in the long term due to a combination of:

- drain clogging due to chemical precipitation
- root activity following the development of tree cover on the embankments
- frost action or freezing of the outlets
- solifluction and deposition of sediments on the outlets
- fines migration into the drains

Dam B at the Ontario site, while it does not have a drainage layer, is subject to high seepage rates. The larger void spaces in the waste rock fill will require a larger quantity of infilling before free drainage is inhibited. As there is no filter installed between the tailings and the waste rock embankment it is anticipated that long term internal erosion and piping may transport tailings into the waste rock voids and result in an elevated phreatic surface. Thus it is again considered that there is a moderate potential of instability in the very long term.

For the Saskatchewan embankments, slopes constructed at a 6:1 slope would be stable for the expected range of pore water conditions and changes in the shear strength. However, the stability of the impoundment would be inadequate if the slope is steepened by solifluction, surface erosion (gullying), piping or a combination of these factors. The initial 6:1 slopes are not necessarily stable in the long run. For instance, development of a phreatic surface may lead to piping, or enhanced mass wasting due to solifluction, either of which could steepen the slopes. If the processes developed until the slope approaches a 2:1 ratio, overall slope failure could occur. Such extensive erosion and failure of 6:1

TABLE V.2-2

CALCULATED FACTORS OF SAFETY

SHEAR STRENGTH* (degrees)	PORE WATER PRESSURE PARAMETER, ru	SLOPE ANGLE 2:1	6:1
38	0.0	1.55	4.25
	0.2	1.11	3.38
	0.4	0.77	2.51
35	0.0	1.40	3.84
	0.2	1.05	3.04
	0.4	0.70	2.25

* zero cohesion, shear strength represented by internal angle of friction

(derived from Bishop and Morgenstern, 1960)

slopes on which good tree cover has been established is considered to have a very low probability of occurrence.

V.2.6 SEEPAGE EROSION

The potential for seepage erosion failure of the three generic tailings embankments is considered in this section. Since the dams have been designed to be stable against internal erosion such failures will not occur unless:

(i) cracks develop in the low permeability barrier layers allowing seepage and pressures to be transmitted through these barriers,

(ii) internal drainage layers fail resulting in a raising of the phreatic surface producing pore pressures and seepage gradients for which the embankments were not designed.

V.2.6.1 Tailings Site Embankments, Ontario

(i) Embankment A (Refer Figures II.2.2-1 and II.2.4-1)

Seepage erosion failure can only occur if the till core cracks and the filter downstream of the core as well as the toe drains block. This combination is considered highly unlikely.

(ii) Embankment B (Refer Figures II.2.2-1 and II.2.4-1)

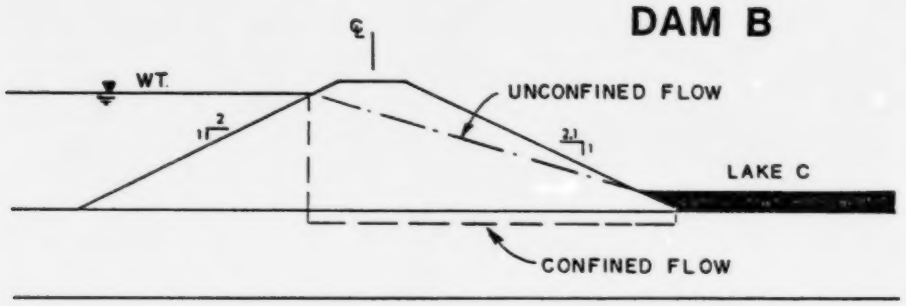
The tailings have been deposited against the un-zoned waste rock embankment. Hydraulic gradients in the tailings against the upstream face could approach 1.0. Creep coefficients of near unity are applicable and internal erosion (refer Table III.8-2) of tailings into the voids in the waste rock can be anticipated in both the short and the long term. As the tailings are piped into the waste rock it will become a less effective drain and mounding of the phreatic surface may occur. In the worst case the waste rock could be completely filled in with tailings and the phreatic surface would be at the surface of the tailings. This situation is illustrated in Figure V.2-1(a). Two flow paths are illustrated as the unconfined and confined flow paths.

Global gradient for unconfined flow (refer to Figure III.8-2). $= \frac{12}{40} = .30$

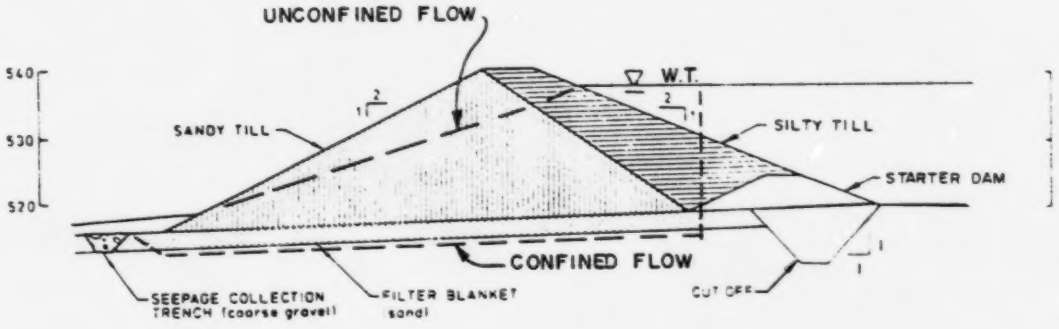
Weighted creep ratio for confined flow $= \frac{60/3}{12} = 1.67$

Comparing these values with the limiting values suggested by Chugaev (Table III.8-5) and Lane (Table III.8-2) indicates that the values are low or marginal and that continued piping of the tailings into the rock waste and ultimately seepage erosion of the embankment may occur if there is not a substantial lowering of the water table in the impoundment following decommissioning.

Such a lowering would not occur if a water cover were placed on this impoundment.



a) ONTARIO DAM B TAILINGS EMBANKMENT SHOWING SEEPAGE PATHS



b) SASKATCHEWAN WET TAILINGS EMBANKMENT SHOWING SEEPAGE PATHS

FLOW PATHS ANALYZED FOR SEEPAGE EROSION

FIGURE V.2-1

V.2.6.2 Wet Tailings Site Embankment, Saskatchewan

Seepage through the embankment of the Saskatchewan wet tailings site is controlled by a sloping core of silty till and a filter blanket which underlies the embankment. No seepage erosion is anticipated if the core remains intact and the filter blanket drain continues to function. The drain may cease functioning for any one of the reasons given for drain clogging in section V.2.5. The core could become more permeable as result of a period of frost aggradation followed by a period of degradation. The core material is frost susceptible.

If the entire underdrainage system is blocked then potential flow paths for confined and unconfined flow are as illustrated in Figure V.2-1(b).

Global gradient for unconfined flow (refer to Figure III.8-2). $= \frac{20}{65} = 0.31$

Weighted creep ratio for confined flow $= \frac{85/3}{20} = 1.4$

Comparing these values with those given in Tables III.8-2 and 5 indicates that if the drains block, resulting in a high phreatic surface in the impoundment then piping and seepage erosion type failures are possible in this embankment. In section V.3.4 an estimate is made of infiltration and seepage rates into and from this impoundment. This indicates that, in the absence of an infiltration inhibiting barrier layer in the cover and if the drains were blocked, a high phreatic surface would result.

It is concluded that seepage erosion and piping failures could occur if all of the following four conditions are satisfied:

(i) an infiltration barrier is not included in the tailings cover

(ii) the filter drain fails

(iii) the slopes are not flattened from the current slopes of 2:1

(iv) a period of frost aggradation and degradation results in an increase in the permeability of the silty till core.

It is considered unlikely that all four conditions will occur.

Another failure mode which is more likely would result if the exits to the drainage blanket blocked (due to freezing for example). With continued water drainage into the blanket, hydraulic heads would build up in the drainage layer behind the blockage. This would give rise to high seepage gradients along flow paths which bypass the blockage and may result in piping and local failures in the toe region of the slope.

V.2.6.3 Semi-dry Tailings Site Embankment, Saskatchewan

The semi-dry tailings deposit is designed to have a zero hydraulic head at all locations within the tailings mass following decommissioning. To achieve this the underdrainage system must remain functional. If all components function as designed then there is no potential for seepage erosion type failures. However, should part or all of the drainage system become blocked for any of the reasons listed in section V.2.5, then there is a potential for the water level to mound within the impoundment. Such a mounding would result in a high pressure head on the relatively thin bentonite modified under-seal. Seepage gradients conducive to seepage erosion and piping would result.

It is concluded that if underdrain blockage did occur, there would be a high probability of piping and seepage erosion of the underseal.

V.3.0 EVALUATION OF STABILITY OF OTHER STRUCTURES

V.3.1 LINERS

V.3.1.1 Typical Tailings Site, Ontario

Since liners and low permeability cut-off zones have not been installed in the impoundment basin or dam B, long term seepage is expected to be high but stable.

Seepage through dam A is controlled by a low permeability glacial-till core and a grout curtain through the upper more permeable bedrock zone. The stability of these are considered in section V.3.4.

V.3.1.2 Wet Tailings Site, Saskatchewan

The seepage barrier at the W.T. site is compacted silty till. As discussed in Section IV.5.1, these materials are relatively inert in the presence of uranium tailings leachates and little long-term increase in permeability is expected. However, as illustrated in Section V.2.4, it is expected that permafrost will aggrade in the pond and embankments. Since the material is very frost susceptible, the development of ice lenses within the embankment can be expected. Should a change in climate or surface conditions occur, causing subsequent thawing, thaw consolidation is a significant risk. The high gradient set up by thaw consolidation would produce a threat of piping and, after numerous freeze/thaw cycles, subsequent catastrophic release of tailings.

V.3.1.3 Semi-dry Tailings Site, Saskatchewan

The S.D. site incorporates a bentonite modified till seal through the embankment and under the pond. This material contains approximately 4 percent bentonite by weight of dry soil and was molded and compacted at a water content below optimum. At all locations, cover on the barrier is in the excess of the maximum expected depth of frost penetration. Since the liner was placed in a dry condition and compacted to a high density, its low permeability characteristics did not depend upon the swelling nature of the bentonite. Hence the potential for long-term deterioration is small. According to Clifton Associates Ltd. (1986) a minor increase in permeability in the long-term (1,000 to 10,000 years) is expected. There are insufficient data to estimate the increased contaminant transfer rate.

V.3.2 EVALUATION OF DIVERSION STRUCTURES

V.3.2.1 Typical Tailings Site, Ontario

The only control structure at the Ontario site is a spillway located at Dam B to decant water from the surface of the impoundment. However, prior to evaluating the consequences of a failure of the spillway it is worth considering the benefits associated with locating a diversion ditch around the impoundment perimeter.

It was noted in section V.1.3 that 200 ha of forest area discharges to the impoundment surface. If a diversion ditch was provided to convey storm

runoff from the forest area around the impoundment there would be a significant reduction in the susceptibility of the cover to gully erosion. The gully erosion tributary area would be reduced from over 2200 sq.m. (24 000 sq. ft.) to about 300 sq.m. (3 300 sq. ft.) This would result in the following changes in the depth of incision after 200 years:

1) Tailings or till cover: about 2 m (from 4 m)

2) Waste rock cover: no incision (from 1 m)

The upstream diversion channel would also reduce rill erosion by about 50 percent.

The spillway structure is provided to decant flows from the entire catchment area of 360 ha. However, if the structure was blocked storm runoff would discharge over the embankment resulting in an increased susceptibility to gully erosion.

The method used for gully erosion estimates for the cover and embankment slopes is not considered appropriate for erosion estimates associated with the large flows that would occur. Temporarily increased flows may result as the embankment crest breaches, releasing stored water. Rapid erosion is anticipated, leading to embankment failure. The long term stability of the embankment is therefore dependent on the long term functioning of the spillway. Experience in the maintenance of water retaining dam spillways has indicated a high likelihood of at least temporary failure due to:

(i) vegetation growth in the spillway
(ii) debris blockage (Beaver dams or natural debris accumulation)
(iii) ice blockage
(iv) sedimentation in the flow channel upstream of the spillway, blocking off flow to the spillway

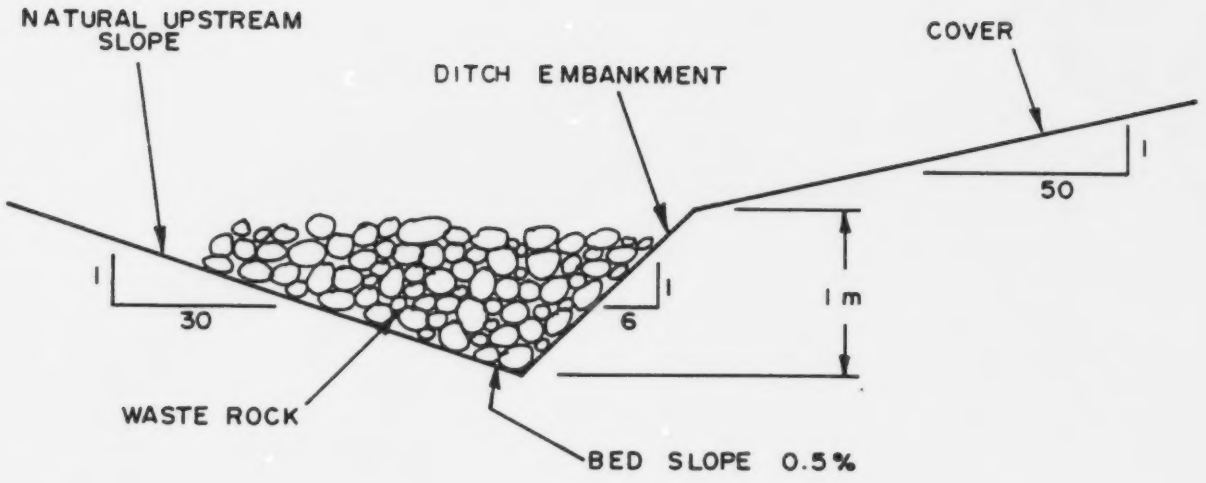
V.3.2.2 Wet Tailings Site, Saskatchewan

As discussed earlier, storm runoff from an upstream forested area is diverted around the impoundment (see Figure II.3.4-7). A sketch of the diversion system is shown in Figure V.3-1. It can be seen that if the waste rock channel is overtopped cover material could be eroded.

Estimated peak flows from the forested area are:

1) 10 year 24 hour event: 2.2 m^3/s
2) 25 year 24 hour event: 2.9 m^3/s
3) 50 year 24 hour event: 3.7 m^3/s
4) 100 year 24 hour event: 5.0 m^3/s
5) PMP event: 24.6 m^3/s

The waste rock channel is sized so that it can convey the 100 year 24 hour event without overtopping the waste rock. However, it is anticipated that periodically the waste rock will be covered with sediment. In this event, flooding of the toe of the unprotected cover could occur up to a depth of 0.5 metres. Flooding would also occur if channel blockage occurred for any



DIVERSION DITCH CROSS-SECTION

FIGURE V.3-1

of the reasons outlined in the discussion above. Severe erosion would occur if the cover material was tailings or till.

Using the results obtained from the WASHED model it is anticipated that up to 0.2 m of material would be eroded by the 2 year event and over 1 m could be eroded by the 100 year event. PMF flows would probably cause localized failures along the perimeter and several metres of material could be removed.

The permissible tractive force for the diversion is estimated as about 0.15 lb/ft^2 and from Figure III.2-14 in Technical Memorandum III it is seen that the cover would need to be protected by material with a D_{50} particle diameter of over 10 mm.

It is concluded that the diversion ditch, as proposed would fail within a number of years of decommissioning resulting in severe erosion of the adjacent cover materials.

V.3.2.3 Semi-dry Tailings Site, Saskatchewan

A diversion structure is located around the upslope perimeter of the impoundment (Figure II.4.4-5). Overtopping of the diversion will result in flooding at the tailings cover. The channel has a steep bed slope of about 2 percent and to prevent severe scour of the embankment, the toe (which forms one side of the diversion) should be protected with riprap material with a D_{50} particle diameter of 40 to 50 mm to a height above which there is little risk of flooding due to diversion blockage.

For the Saskatchewan Semi-dry Tailings Site it was assumed in Sections V.1.3 and V.2.1 that runoff from the top cover would be controlled along the crest of the containment embankment. However, if runoff overtops the embankment crests there could be a significant increase in erosion losses from the embankments.

It is anticipated that rill erosion due to severe events would be increased by a factor of 20. This would result in severe side slope failures.

The embankments would also be more susceptible to gully erosion and the potential would exist for a total loss of the embankment and complete failure of the structure in the long term.

V.3.3 SURFACE WATER QUALITY CONTROL MEASURES

V.3.3.1 Typical Tailings Site, Ontario

As noted in II.2.4.6, all surface drainage plus seepage at a rate of 2.1 L/s is collected in a pond and treated with lime and barium chloride prior to discharge into Lake C. As no water storage is done on the impoundment cover, the storage pond must be large enough to regulate the storm water runoff from the entire impoundment area of 360 ha. Discharge and flow control structures will require maintenance.

The lime and barium chloride treatment works and supplies must be maintained and serviced on a continuous basis. Barium and other metal precipitates will continue to accumulate in Lake C, which must be isolated from human access and usage.

It is concluded that the storage, treatment and release of surface waters at the typical Ontario site will require continuous long term maintenance.

V.3.3.2 Wet Tailings Site, Saskatchewan

It is anticipated that after a time the quality of surface water discharge will improve to a level at which it can be discharged, regardless of the nature of the surface cover. Infiltration and therefore seepage will depend on the cover type and will range from 27,000 to 144,000 m^3/year as indicated on Table V.3-1. Initially the chemical quality of this water may be similar to that of the tailings discharge water (Table II.3.3-3) but is expected to improve over the long term. The extent of this improvement was not evaluated in this study.

Discontinuation of the treatment works will result in contaminant seepage water releases.

V.3.3.3 Semi-dry Tailings Site, Saskatchewan

As for the wet site, the infiltration rate will be controlled by the type of cover placed. Infiltration estimates are given on Table V.3-1 and range from 22,500 to 120,000 m^3/year. This infiltration is expected to report, as contaminated seepage to the underdrain from where it will seep into the underlying foundation soils (through the soil-bentonite seal) or discharge from the underdrain exit point. Initial seepage water qualities may be close to that of the tailings pore water (Table II.4.3-3) but this is expected to change with time.

Discontinuation of the treatment works will result in contaminated seepage water releases.

V.3.4 SEEPAGE CONTROL STRUCTURES

V.3.4.1 Wet Tailings Site, Saskatchewan

A simplified seepage analysis was carried out on the W.T. site, for post decommissioned conditions. The decommissioned geometry illustrated in Figures II.3.4-7 and II.3.4-8 was used. A full 3 m cover and no cover were considered with functional and blocked embankment drains. Flow net and simple linear flow analytical techniques were used.

TABLE V.3-1

SUMMARY OF ANNUAL AVERAGE INFILTRATION RATES
AND AMOUNTS AT SASKATCHEWAN SITES

	W.T. SITE	S.D. SITE
Precipitation (mm)	400	415
Cover Area (ha)	90	75
Bare Tailings		
Depth of annual infiltration (mm/year)	80	80
Volume of annual infiltration (m^3/year)	72,000	60,000
Waste Rock Cover		
Depth of annual infiltration (mm/year)	160	160
Volume of annual infiltration (m^3/year)	144,000	120,000
Forested Cover		
Depth of annual infiltration (mm/year)	40	40
Volume of annual infiltration (m^3/year)	36,000	30,000
Bentonite Modified Infiltration Barrier		
Depth of annual infiltration (mm/year)	30	30
Volume of annual infiltration (m^3/year)	27,000	22,500

The following table presents the soil hydraulic conductivity values.

MATERIAL	HYDRAULIC CONDUCTIVITY (m/s)
Embankment till	1×10^{-6}
Tailings	5×10^{-6}
Till	1×10^{-6}
Bedrock	1×10^{-7}
Soil bentonite cover	1×10^{-9}

Infiltration estimates for covers without seepage barriers were made in section V.1.5 and are summarized in Table V.3-1.

The potential cover leakage through the thick (3000 mm) cover with a bentonite modified barrier was estimated assuming partially dewatered tailings below the cover (when the soil bentonite cover is subjected to a unit gradient). The resulting leakage is 30 mm/year or 27,000 m^3 per year over the 90 ha cover. The rate of infiltration is greater than the rate of leakage through the barrier. The excess water will tend to pond in the rock layer above the barrier. The transmissivity of the rock layer is sufficient to conduct the excess water to the edge of the cover without water mounding in the rock.

Flow into the embankment drains and flow through the embankment under blocked drainage conditions were evaluated by flow net techniques. Complete consolidation of the tailings was assumed. The potential, assuming the water table in the tailings remains 1 m from surface is 1.5 m^3/metre length/day. Discharge to the toe of the reclaimed slope (blocked drains) is 0.3 m^3/metre length/day.

For the 1200 m long embankment this implies drainage from the impoundment of up to 328,500 m^3 per year prior to reclamation and at 65,700 m^3 per year following blockage of drains during decommissioning. It is noted that if high rates of infiltration occur, as with a waste rock cover, then the annual infiltration rate exceeds the seepage rate with the drains blocked. Blockage of the drains may therefore result in mounding of the water level within the tailings pond to the level of the cover. This could result in contaminated water discharges from the upper surface of the tailings impoundment.

It is noted that in order to prevent mounding in the tailings a seepage rate equivalent at least to the average annual infiltration rate must occur. This rate has been estimated at between 27,000 m^3 per year (or 50 litres per minute) and 144,000 m^3 per year (273 litres per minute) depending on the nature of the cover material.

The cover condition therefore controls the amount of infiltration and the discharge throughout the embankment or into the drainage system.

The capacity of the tailings to conduct fluid to the drain without creating a substantial groundwater mound in the tailings was also investigated. For

no cover conditions a head differential of 16 m above mid height of the embankment was required at the upstream end of the impoundment. This would result in groundwater mounding to the tailings surface which would prevent tailings dewatering in the upstream portion of the tailings impoundment. For the 3 m cover, which includes an infiltration barrier, the head needed was reduced to 7 m above mid height of the embankment, which would be below the top of tailings.

V.3.4.2 Semi-dry Tailings Site, Saskatchewan

A simplified seepage analysis was carried out at the S.D. site for post decommissioned conditions. The decommissioned geometry is illustrated in Figures II.4.4-5 and II.4.4-6. A full 3 m cover and no cover conditions were considered with functional and blocked embankment drains. Simple linear flow analytical techniques were used.

The following table presents the soil hydraulic conductivity values.

Material	Hydraulic Conductivity (m/s)
Embankment/till	1×10^{-6}
Tailings	1×10^{-7}
Soil Bentonite - underseal	1×10^{-9}
Soil Bentonite - cover	1×10^{-9}
Underdrain	1×10^{-5}

As for the W.T. site, the maximum flow through the cover is 30 mm/year.

The liner system consists of a seal and drain under the tailings. The drain maintains a very low or negative gradient across the underseal thereby limiting release to the surrounding groundwater system.

The underdrain conducts seepage from the tailings downstream from the embankment to where it is treated and released. The capacity of the drain is critical as it must carry infiltration water up to 1100 m to the discharge point. A drain consisting only of 1 m of sand is overloaded. A groundwater mound develops within the tailings and would saturate the cover within 30 to 150 m of the embankment. A drain tile system is therefore required within the drain layer for proper functioning.

If the drain becomes blocked, the water level in the tailings will rise and exert a significant hydrostatic head across the underseal. In this case, the release would be approximately equal to infiltration. The potential flow through the underseal, if the head is allowed to rise to the tailings surface, is greater than the annual precipitation. Thus the water table in the tailings cannot mound to the cover surface.

The soil bentonite embankment core is very effective. If the tailings water level rises to surface, the flow through the embankment core is approximately 7 m^3/day.

In summary, the proper and continued function of the drain is essential for proper operation of the containment system. Drain blockage or omission of the drainage pipes will allow the head in the tailings to rise significantly and cause flow, approximately equal to infiltration, through the underseal and over the core in the embankments.

In the long term there is the potential for blockage of these underdrains due to one of the following:

(i) salt precipitation
(ii) frost action or freezing
(iii) piping in of fines into the void spaces
(iv) aging and collapse of the drain tiles
(v) slumping or sediment covering the exit points
(vi) root action by tree cover on the embankments

Each of these mechanisms must be evaluated in order to determine the potential for failure. Based on the general assessments made in this study it is concluded that the potential for failure by at least one of these mechanisms is moderate to severe.

V.3.4.3 Typical Tailings Site, Ontario

Water balance calculations have not been repeated for the Ontario Tailings Site. Essentially the same concerns and observations apply as for the Saskatchewan Wet Tailings site with regard to the potential for the mounding of the water table within the tailings and long term seepage (see V.3.4.2). Because of the higher net precipitation at Elliot Lake the infiltration potential is greater for all cover types.

An additional concern at Dam A at the Ontario site is the long term stability of the grout curtain. While the grout curtain was formed using sulphate resistant cement, its stability against the long term attack of acidic tailings solutions is questionable. The rate at which the grout will leach out will depend on the acidity and sulphate content of the leaching water, as well as the seepage rates. In the absence of acid seepage, the grout curtain will be stable in the long term. In view of the uncertainty as to acid generation in the 1000 to 2000 year term the potential for instability of the grout curtain is considered to be moderate to high.

V.4.0 REFERENCES

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Lane, E.W. 1935. Security from Under-Seepage: Masonry Dam on Earth Foundations, Trans. ASCE, pp. 1235-12272, Discussion, pp. 1273-1351.

APPENDIX V.1.2

WASHED OUTPUT FILE FOR TYPICAL ONTARIO TAILINGS SITE COVER

```
**********************************************************
*                                                        *
*      H Y D R O L O G I C A L    S Y S T E M S          *
*                                                        *
**********************************************************
*                                                        *
*              PROGRAM   -   WASHED                      *
*                                                        *
*              WATERSHED MODELLING                       *
*                                                        *
*        PROGRAM TO DETERMINE RUNOFF HYDROGRAPHS         *
*        AND SEDIMENTGRAPHS FOR SMALL CATCHMENTS         *
*                                                        *
**********************************************************

COMPANY DOING ANALYSIS :   SRK
ENGINEER               :   ANDY WARD
DATE                   :   14-MAR-86
CLIENT                 :   CANMET
PROJECT DESCRIPTION    :   TAILINGS COVER
MAJOR WATERSHED NAME   :   ELLIOT LAKE

THE INPUT DATA FILE IS                    :ELLIOT
THE FLOOD HYDROGRAPH AND SEDIMENTGRAPH IS NOT STORED

**********************************************************
WATERSHED CONDITIONS AT  ELLIOT LAKE
**********************************************************

GLOBAL PARAMETERS
-----------------

RAINFALL                                    (mm.)    :    11[illegible].00
INITIAL ABSTRACTION                         (mm.)    :         .00
  -- will default to the SCS method
TIME INCREMENT OF HYDROGRAPH FROM START OF RUNOFF    :         .20

RAINFALL DISTRIBUTION SELECTED                  :SCS TYPE 2 [illegible]E
```

****
SUBWATERSHED CONDITIONS AT FOREST
****

RAINFALL PARAMETERS

SCS CURVE NUMBER		:	80.00
UNIT HYDROGRAPH SELECTED		:	DOUBLE TRIANGLE

MAP PARAMETERS

AREA	(ha.)	:	200.00
HYDRAULIC LENGTH	(m.)	:	1000.00
PERCENT FOREST	(%)	:	75.00
PERCENT AGRICULTURE	(%)	:	.00
PERCENT GRASSLAND	(%)	:	25.00
OVERLAND FLOW SLOPE	(%)	:	15.00
CHANNEL SLOPE	(%)	:	.50
CHANNEL LENGTH FROM SUBWATERSHED	(m.)	:	1500.00
TYPE OF CHANNEL FROM SUBWATERSHED		:	A NATURAL STREAM
CORRECTION FACTOR FOR IMPERVIOUS AREA		:	1.00
CORRECTION FACTOR FOR CHANNEL IMPROVEMENTS		:	1.00
AREAL REDUCTION FACTOR		:	1.00

SEDIMENT PARAMETERS

SOIL ERODIBILITY PARAMETER K		:	.25
OVERLAND FLOW LENGTH	(m.)	:	1000.00
ERODIBLE AREA SLOPE	(%)	:	.50
COVER OR CONSERVATION PRACTICE FACTOR		:	1.00
SPECIFIC GRAVITY OF THE SEDIMENT PARTICLES		:	2.65
EXPONENT OF THE FLOW SEDIMENT LOAD RELATIONSHIP		:	2.00

PARTICLE SIZE DISTRIBUTION OF SEDIMENT FLOW

PART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0

********** STORM HYDROGRAPH GENERATED FROM START OF RAINFALL **********

TIME *	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8.0 *	.0	.0	.0	.0	.0	.0	.1	.1	.1	.1
9.0 *	.1	.1	.1	.1	.1	.2	.2	.2	.2	.2
10.0 *	.2	.3	.3	.3	.3	.3	.3	.4	.4	.4
11.0 *	.4	.5	.5	.5	.6	.7	.8	1.0	1.4	2.0
12.0 *	3.0	4.3	5.6	6.8	7.7	8.4	8.5	8.3	8.1	7.8
13.0 *	7.5	7.3	7.0	6.6	6.3	6.0	5.6	5.3	4.9	4.6
14.0 *	4.4	4.3	4.2	4.2	4.1	4.0	3.9	3.8	3.7	3.6
15.0 *	3.5	3.4	3.3	3.3	3.2	3.1	3.1	3.0	3.0	2.9
16.0 *	2.9	2.9	2.8	2.8	2.8	2.7	2.7	2.7	2.6	2.6
17.0 *	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.3	2.3	2.2
18.0 *	2.2	2.1	2.1	2.1	2.0	2.0	1.9	1.9	1.9	1.8
19.0 *	1.8	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.4	1.4
20.0 *	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.1
21.0 *	1.0	1.0	1.0	1.0	1.0	.9	.9	.9	.9	.9
22.0 *	.9	.9	.8	.8	.8	.8	.8	.8	.8	.7
23.0 *	.7	.7	.7	.7	.7	.7	.6	.6	.6	.6
24.0 *	.6	.6	.6	.5	.5	.5	.5	.4	.4	.4
25.0 *	.4	.4	.3	.3	.3	.3	.3	.3	.2	.2
26.0 *	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2
27.0 *	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
28.0 *	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
29.0 *	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
30.0 *	.0	.0	.0	.0	.0	.0	.0	.0		

INITIAL ABSTRACTION	=	12.70	mm.
ROUTED FLOW TIME FROM THE SUBWATERSHED	=	.95	hours.
TIME TO PEAK OF UNIT HYDROGRAPH	=	.60	hours.
THE DEPTH OF WATER ON WATERSHED	=	63.11	mm.
VOLUME OF RUNOFF	=	126.17	thousand cu.m.
PEAK RUNOFF RATE	=	8.55	cu. m./sec.
TIME TO PEAK RUNOFF	=	12.60	hours.

****** STORM SEDIMENTOGRAPH GENERATED FROM START OF RAINFALL ******

TIME *	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1
8.0 *	.2	.2	.3	.4	.5	.6	.7	.8	.9	1.1
9.0 *	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.4	2.6	2.8
10.0 *	3.0	3.2	3.4	3.6	3.9	4.1	4.3	4.6	4.9	5.1
11.0 *	5.4	5.7	6.0	6.5	7.3	8.5	10.2	13.2	18.8	27.7
12.0 *	41.4	58.0	73.7	87.8	98.9	105.6	106.0	103.2	100.1	96.8
13.0 *	93.3	89.7	85.8	81.8	77.6	73.4	69.1	64.8	60.7	57.3
14.0 *	54.8	53.6	52.9	52.0	50.9	49.7	48.4	47.0	45.8	44.6
15.0 *	43.5	42.4	41.4	40.6	39.7	39.0	38.3	37.6	37.0	36.5
16.0 *	36.0	35.6	35.2	34.8	34.4	33.9	33.5	33.1	32.6	32.2
17.0 *	31.7	31.3	30.8	30.4	29.9	29.4	29.0	28.5	28.0	27.5
18.0 *	27.0	26.5	26.0	25.5	25.0	24.5	24.0	23.5	23.0	22.5
19.0 *	22.0	21.4	20.9	20.4	19.8	19.3	18.8	18.2	17.7	17.1
20.0 *	16.6	16.1	15.5	15.0	14.5	14.1	13.8	13.5	13.3	13.1
21.0 *	12.8	12.6	12.4	12.2	11.9	11.7	11.5	11.3	11.1	10.9
22.0 *	10.8	10.6	10.4	10.2	10.0	9.9	9.7	9.6	9.4	9.2
23.0 *	9.1	8.9	8.7	8.6	8.4	8.2	8.1	7.9	7.7	7.6
24.0 *	7.4	7.2	7.0	6.7	6.5	6.1	5.8	5.5	5.2	4.9
25.0 *	4.6	4.3	4.1	3.9	3.7	3.5	3.3	3.1	3.0	2.8
26.0 *	2.7	2.6	2.5	2.4	2.3	2.2	2.2	2.1	2.0	1.9
27.0 *	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2
28.0 *	1.1	1.1	1.0	1.0	.9	.9	.8	.8	.7	.7
29.0 *	.6	.6	.6	.5	.5	.4	.4	.4	.4	.3
30.0 *	.3	.3	.3	.2	.2	.2	.2	.1		

SEDIMENT YIELD	=	7734.98	tonnes.
PEAK SEDIMENT CONCENTRATION	=	106.05	mg/l.
TIME TO PEAK SEDIMENT CONCENTRATION	=	12.60	hours.

****
SUBWATERSHED CONDITIONS AT TAILINGS
****

RAINFALL PARAMETERS

SCS CURVE NUMBER	: 80.00
UNIT HYDROGRAPH SELECTED	: DOUBLE TRIANGLE

MAP PARAMETERS

AREA	(ha.)	:	160.00
HYDRAULIC LENGTH	(m.)	:	1500.00
PERCENT FOREST	(%)	:	.00
PERCENT AGRICULTURE	(%)	:	.00
PERCENT GRASSLAND	(%)	:	.00
OVERLAND FLOW SLOPE	(%)	:	.50
CHANNEL SLOPE	(%)	:	.50
CHANNEL LENGTH FROM SUBWATERSHED	(m.)	:	.00
TYPE OF CHANNEL FROM SUBWATERSHED		:	A NATURAL STREAM
CORRECTION FACTOR FOR IMPERVIOUS AREA		:	1.00
CORRECTION FACTOR FOR CHANNEL IMPROVEMENTS		:	1.00
AREAL REDUCTION FACTOR		:	1.00

SEDIMENT PARAMETERS

SOIL ERODIBILITY PARAMETER K		:	.25
OVERLAND FLOW LENGTH	(m.)	:	1000.00
ERODIBLE AREA SLOPE	(%)	:	.50
COVER OR CONSERVATION PRACTICE FACTOR		:	1.00
SPECIFIC GRAVITY OF THE SEDIMENT PARTICLES		:	2.65
EXPONENT OF THE FLOW SEDIMENT LOAD RELATIONSHIP		:	2.00

PARTICLE SIZE DISTRIBUTION OF SEDIMENT FLOW

PART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0

********** STORM HYDROGRAPH GENERATED FROM START OF RAINFALL **********

TIME *	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8.0 *	.0	.0	.0	.0	.0	.1	.1	.1	.1	.1
9.0 *	.1	.1	.1	.1	.2	.2	.2	.2	.2	.2
10.0 *	.3	.3	.3	.3	.3	.3	.4	.4	.4	.4
11.0 *	.4	.5	.5	.5	.6	.7	.9	1.2	1.8	2.7
12.0 *	4.1	5.9	7.7	9.2	10.3	10.8	10.2	8.9	7.6	6.4
13.0 *	5.4	4.8	4.7	4.6	4.6	4.5	4.5	4.4	4.4	4.3
14.0 *	4.2	4.2	4.1	3.9	3.8	3.7	3.5	3.3	3.2	3.0
15.0 *	2.9	2.8	2.7	2.6	2.5	2.5	2.4	2.3	2.2	2.1
16.0 *	2.0	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.4	1.3
17.0 *	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1
18.0 *	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.9	.9	.9
19.0 *	.9	.9	.9	.9	.9	.9	.8	.8	.8	.8
20.0 *	.8	.8	.8	.8	.8	.8	.7	.7	.7	.7
21.0 *	.7	.7	.7	.7	.7	.7	.6	.6	.6	.6
22.0 *	.6	.6	.6	.6	.6	.5	.5	.5	.5	.5
23.0 *	.5	.5	.5	.5	.5	.4	.4	.4	.4	.4
24.0 *	.4	.4	.4	.3	.3	.3	.3	.2	.2	.2
25.0 *	.2	.2	.1	.1	.1	.1	.1	.1	.1	.1
26.0 *	.1	.1	.1	.1	.1	.1	.1	.0	.0	.0
27.0 *	.0	.0	.0	.0	.0	.0	.0	.0		

INITIAL ABSTRACTION	=	12.70	mm.
ROUTED FLOW TIME FROM THE SUBWATERSHED	=	.00	hours.
TIME TO PEAK OF UNIT HYDROGRAPH	=	.60	hours.
THE DEPTH OF WATER ON WATERSHED	=	63.11	mm.
VOLUME OF RUNOFF	=	100.94	thousand cu.m.
PEAK RUNOFF RATE	=	10.76	cu. m./sec.
TIME TO PEAK RUNOFF	=	12.50	hours.

==========

****** STORM SEDIMENTGRAPH GENERATED FROM START OF RAINFALL **********

TIME *	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7.0 *	.0	.0	.0	.0	.0	.0	.0	.1	.1	.1
8.0 *	.2	.3	.3	.4	.5	.6	.7	.8	.9	1.1
9.0 *	1.2	1.3	1.4	1.6	1.7	1.9	2.0	2.2	2.3	2.5
10.0 *	2.7	2.9	3.1	3.2	3.4	3.6	3.9	4.1	4.3	4.5
11.0 *	4.7	5.0	5.3	5.8	6.6	7.9	9.9	13.4	20.2	30.9
12.0 *	47.2	67.0	85.1	100.4	110.4	112.5	104.1	90.1	76.4	64.5
13.0 *	55.1	49.9	48.9	48.5	48.0	47.5	47.0	46.4	45.7	45.1
14.0 *	44.4	43.6	42.5	41.2	39.7	38.1	36.2	34.4	32.8	31.4
15.0 *	30.2	29.2	28.3	27.4	26.6	25.7	24.8	23.9	23.0	22.1
16.0 *	21.2	20.3	19.4	18.5	17.6	16.7	15.9	15.1	14.3	13.8
17.0 *	13.4	13.1	12.8	12.5	12.3	12.0	11.8	11.6	11.4	11.2
18.0 *	11.0	10.8	10.6	10.4	10.3	10.2	10.0	9.9	9.8	9.7
19.0 *	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.8	8.7	8.6
20.0 *	8.5	8.4	8.3	8.2	8.0	7.9	7.8	7.7	7.6	7.5
21.0 *	7.4	7.3	7.2	7.1	7.0	6.8	6.7	6.6	6.5	6.4
22.0 *	6.3	6.2	6.1	6.0	5.9	5.7	5.6	5.5	5.4	5.3
23.0 *	5.2	5.1	5.0	4.9	4.7	4.6	4.5	4.4	4.3	4.2
24.0 *	4.1	3.9	3.7	3.5	3.3	3.0	2.6	2.3	2.1	1.9
25.0 *	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	.9
26.0 *	.8	.8	.7	.7	.6	.6	.5	.5	.4	.4
27.0 *	.3	.3	.3	.2	.2	.2	.2	.1		

SEDIMENT YIELD	=	3624.10	tonnes.
PEAK SEDIMENT CONCENTRATION	=	112.53	mg/l.
TIME TO PEAK SEDIMENT CONCENTRATION	=	12.50	hours.

STORM HYDROGRAPH FOR WATERSHED ELLIOT LAKE

TOTAL AREA OF THE WATERSHED	=	360.00	ha.
THE DEPTH OF WATER ON WATERSHED	=	63.11	mm.
VOLUME OF RUNOFF	=	227.09	thousand cu.m.
PEAK RUNOFF RATE	=	13.06	cu. m./sec.
TIME TO PEAK RUNOFF	=	13.50	hours.
TIME INCREMENT OF NEW HYDROGRAPH	=	.20	hours.
NUMBER OF RUNOFF VALUES	=	121	

******* STORM HYDROGRAPH GENERATED FROM START OF RUNOFF *****

.0	.0	.0	.0	.1	.1	.1	.1	.2	.2
.3	.3	.4	.4	.5	.6	.6	.7	.8	1.1
1.6	3.1	6.4	9.8	11.5	10.1	8.9	9.8	11.9	13.1
12.6	12.0	11.3	10.4	9.5	8.4	7.5	7.1	6.8	6.4
6.0	5.7	5.3	5.0	4.7	4.5	4.2	4.1	4.0	3.9
3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0	2.9	2.8
2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8
1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2
1.2	1.1	1.1	1.0	.9	.9	.8	.7	.7	.6
.5	.5	.4	.4	.3	.3	.3	.2	.2	.2
.2	.2	.1	.1	.1	.1	.1	.1	.1	.1
.1	.1	.0	.0	.0	.0	.0	.0	.0	.0
.0									

STORM SEDIMENTGRAPH FOR WATERSHED ELLIOT LAKE

TOTAL SEDIMENT YIELD	=	11359.08	tonnes.
PEAK SEDIMENT CONCENTRATION	=	105.84	mg/l.
TIME TO PEAK SEDIMENT CONCENTRATION	=	12.60	hours.

********* STORM SEDIMENTGRAPH GENERATED FROM START OF RUNOFF ********

.1	.1	.3	.4	.6	.8	1.0	1.2	1.4	1.6
1.8	2.1	2.4	2.8	3.1	3.5	3.9	4.4	5.1	6.7
11.4	27.6	62.8	95.3	105.8	80.6	55.1	58.3	76.5	86.2
82.2	77.1	71.4	65.1	58.4	51.5	46.1	43.8	42.2	40.1
37.9	35.8	34.0	32.5	31.2	30.1	29.3	28.6	27.9	27.3
26.6	25.9	25.2	24.4	23.6	22.9	22.1	21.3	20.4	19.6
18.8	17.9	17.1	16.2	15.4	14.5	13.6	12.8	12.0	11.3
10.9	10.5	10.2	9.8	9.5	9.1	8.8	8.5	8.2	7.9
7.7	7.4	7.1	6.8	6.6	6.4	6.2	6.0	5.6	5.0
4.5	4.0	3.6	3.2	2.9	2.7	2.5	2.3	2.2	2.0
1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.0	.9	.8
.7	.7	.6	.5	.4	.4	.3	.3	.2	.2
.1									

PARTICLE SIZE DISTRIBUTION OF SEDIMENT

WEIGHTED SPECIFIC GRAVITY = 2.65

PART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0

APPENDIX V.1.1

WASHED DATA FILE FOR TYPICAL ONTARIO TAILINGS SITE COVER

ANDY WARD
14-MAR-86
CANMET
TAILINGS COVER
ELLIOT LAKE

GLOBAL PARAMETERS

55.00	RAINFALL	(mm.)
24.00	STORM DURATION	(hours)
.00	INITIAL ABSTRACTION	(mm.)
.20	TIME INCR. OF HYDROGRAPH FROM START OF RUNOFF	
2	RAINFALL DISTRIBUTION : SCS TYPE 2 CURVE	
2	= THE NUMBER OF WATERSHEDS	

****
SUBWATERSHED No. 1 : FOREST
****

RAINFALL PARAMETERS

80.00	SCS CURVE NUMBER	
1	UNIT HYDROGRAPH : DOUBLE TRIANGLE	

MAP PARAMETERS

200.00	AREA	(ha)
1000.00	HYDRAULIC LENGTH	(m.)
75.00	PERCENT FOREST	(%)
.00	PERCENT AGRICULTURE	(%)
25.00	PERCENT GRASSLAND	(%)
15.00	OVERLAND FLOW SLOPE	(%)
.50	CHANNEL SLOPE	(%)
1500.00	CHANNEL LENGTH FROM SUBWATERSHED	(m.)
1	CHANNEL FROM SUBWATERSHED IS A NATURAL STREAM	
1.00	CORRECTION FACTOR FOR IMPERVIOUS AREA	
1.00	CORRECTION FACTOR FOR CHANNEL IMPROVEMENTS	
1.00	AREAL REDUCTION FACTOR	

SEDIMENT PARAMETERS

1	SWITCH FOR SEDIMENT DATA
.25	SOIL ERODIBILITY PARAMETER K
.50	ERODING AREA SLOPE (%)
1000.00	OVERLAND FLOW LENGTH (in m.)
1.00	COVER OR CONSERVATION PRACTICE FACTOR
2.65	SPECIFIC GRAVITY OF THE SEDIMENT PARTICLES
2.40	EXPONENT OF THE FLOW SEDIMENT LOAD RELATIONSHIP

7 THE NUMBER OF PARTICLE SIZE DISTRIBUTION VALUES

ART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0

****
UBWATERSHED No. 2 : TAILINGS
****

AINFALL PARAMETERS

80.00	SCS CURVE NUMBER
1	UNIT HYDROGRAPH : DOUBLE TRIANGLE

AP PARAMETERS

160.00	AREA	(ha)
1500.00	HYDRAULIC LENGTH	(m.)
.00	PERCENT FOREST	(%)
.00	PERCENT AGRICULTURE	(%)
.00	PERCENT GRASSLAND	(%)
.50	OVERLAND FLOW SLOPE	(%)
.50	CHANNEL SLOPE	(%)
.00	CHANNEL LENGTH FROM SUBWATERSHED	(m.)
1	CHANNEL FROM SUBWATERSHED IS A NATURAL STREAM	
1.00	CORRECTION FACTOR FOR IMPERVIOUS AREA	
1.00	CORRECTION FACTOR FOR CHANNEL IMPROVEMENTS	
1.00	AREAL REDUCTION FACTOR	

EDIMENT PARAMETERS

1	SWITCH FOR SEDIMENT DATA
.25	SOIL ERODIBILITY PARAMETER K
.50	ERODING AREA SLOPE (%)
1000.00	OVERLAND FLOW LENGTH (in m.)
1.00	COVER OR CONSERVATION PRACTICE FACTOR

7 THE NUMBER OF PARTICLE SIZE DISTRIBUTION VALUES

PART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0

APPENDIX V.2.1

WASHED DATA FILE FOR TYPICAL ONTARIO TAILINGS SITE EMBANKMENT

```
GRK
ANDY WARD
14-MAR-86
CANMET
TAILINGS COVERS
ELLIOT DAM A

GLOBAL PARAMETERS
-----------------

     55.00      RAINFALL                (mm.)
     24.00      STORM DURATION          (hours)
       .00      INITIAL ABSTRACTION     (mm.)
       .20      TIME INCR. OF HYDROGRAPH FROM START OF RUNOFF

         2      RAINFALL DISTRIBUTION : SCS TYPE 2 CURVE

         1      = THE NUMBER OF WATERSHEDS


**********************
SUBWATERSHED No.    1 : DAM A
**********************

RAINFALL PARAMETERS
-------------------
     80.00      SCS CURVE NUMBER
         0      UNIT HYDROGRAPH : HAANS

MAP PARAMETERS
--------------
       .50      AREA                                    (ha)
     25.00      HYDRAULIC LENGTH                        (m.)
       .00      PERCENT FOREST                          (%)
       .00      PERCENT AGRICULTURE                     (%)
       .00      PERCENT GRASSLAND                       (%)
     50.00      OVERLAND FLOW SLOPE                     (%)
       .50      CHANNEL SLOPE                           (%)
       .00      CHANNEL LENGTH FROM SUBWATERSHED        (m.)
         1      CHANNEL FROM SUBWATERSHED IS A NATURAL STREAM
      1.00      CORRECTION FACTOR FOR IMPERVIOUS AREA
      1.00      CORRECTION FACTOR FOR CHANNEL IMPROVEMENTS
      1.00      AREAL REDUCTION FACTOR

SEDIMENT PARAMETERS
-------------------
         1      SWITCH FOR SEDIMENT DATA
       .25      SOIL ERODIBILITY PARAMETER K
     50.00      ERODING AREA SLOPE (%)
     25.00      OVERLAND FLOW LENGTH (in m.)
      1.00      COVER OR CONSERVATION PRACTICE FACTOR
      2.65      SPECIFIC GRAVITY OF THE SEDIMENT PARTICLES
      2.00      EXPONENT OF THE FLOW SEDIMENT LOAD RELATIONSHIP
```

PARTICLE SIZE DISTRIBUTION OF SEDIMENT FLOW

7 THE NUMBER OF PARTICLE SIZE DISTRIBUTION VALUES

PART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0

APPENDIX V.2.2

WASHED OUTPUT FILE FOR TYPICAL ONTARIO TAILINGS SITE EMBANKMENT

```
==========================================================

  **********************************************************
  *                                                        *
  *      H Y D R O L O G I C A L    S Y S T E M S          *
  *                                                        *
  **********************************************************
  *                                                        *
  *              PROGRAM   -   WASHED                      *
  *                                                        *
  *              WATERSHED MODELLING                       *
  *                                                        *
  *         PROGRAM TO DETERMINE RUNOFF HYDROGRAPHS        *
  *         AND SEDIMENTGRAPHS FOR SMALL CATCHMENTS        *
  *                                                        *
  **********************************************************


 COMPANY DOING ANALYSIS :   SRK
 ENGINEER               :   ANDY WARD
 DATE                   :   14-MAR-86
 CLIENT                 :   CANMET
 PROJECT DESCRIPTION    :   TAILINGS COVERS
 MAJOR WATERSHED NAME   :   ELLIOT DAM A

 THE INPUT DATA FILE IS                    :DAMA
 THE FLOOD HYDROGRAPH AND SEDIMENTGRAPH IS NOT STORED

==========================================================
```

****
WATERSHED CONDITIONS AT ELLIOT DAM A
****

GLOBAL PARAMETERS

RAINFALL	(mm.)	:	115.00
INITIAL ABSTRACTION	(mm.)	:	.00
-- will default to the SCS method			
TIME INCREMENT OF HYDROGRAPH FROM START OF RUNOFF		:	.20

RAINFALL DISTRIBUTION SELECTED :SCS TYPE 2 CURVE

==========

****
SUBWATERSHED CONDITIONS AT DAM A
****

RAINFALL PARAMETERS

SCS CURVE NUMBER	:	80.00
UNIT HYDROGRAPH SELECTED	:	HAANS

MAP PARAMETERS

AREA	(ha.)	:	.50
HYDRAULIC LENGTH	(m.)	:	25.00
PERCENT FOREST	(%)	:	.00
PERCENT AGRICULTURE	(%)	:	.00
PERCENT GRASSLAND	(%)	:	.00
OVERLAND FLOW SLOPE	(%)	:	50.00
CHANNEL SLOPE	(%)	:	.50
CHANNEL LENGTH FROM SUBWATERSHED	(m.)	:	.00
TYPE OF CHANNEL FROM SUBWATERSHED		:	A NATURAL STREAM
CORRECTION FACTOR FOR IMPERVIOUS AREA		:	1.00
CORRECTION FACTOR FOR CHANNEL IMPROVEMENTS		:	1.00
AREAL REDUCTION FACTOR		:	1.00

SEDIMENT PARAMETERS

SOIL ERODIBILITY PARAMETER K		:	.25
OVERLAND FLOW LENGTH	(m.)	:	25.00
ERODIBLE AREA SLOPE	(%)	:	50.00
COVER OR CONSERVATION PRACTICE FACTOR		:	1.00
SPECIFIC GRAVITY OF THE SEDIMENT PARTICLES		:	2.65
EXPONENT OF THE FLOW SEDIMENT LOAD RELATIONSHIP:			2.00

PARTICLE SIZE DISTRIBUTION OF SEDIMENT FLOW

PART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0

****** STORM SEDIMENTGRAPH GENERATED FROM START OF RAINFALL **********

TIME	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7.0	.0	.0	.0	18.3	55.0	94.1	133.0	175.2	215.9	261.2
8.0	303.6	352.2	396.4	448.3	494.4	549.6	597.5	656.2	705.9	768.3
9.0	819.9	885.6	939.0	1008.6	1064.0	1137.0	1194.1	1271.0	1330.0	1410.7
10.0	1471.5	1555.9	1618.5	1706.8	1771.2	1863.3	1929.5	2025.4	2093.3	2199.0
11.0	2270.7	3041.0	3349.4	7006.1	8513.5	13178.1	15451.4	44538.2	59948.5	94808.6
12.0	********	36097.7	12043.8	11568.4	11513.4	11171.3	11108.0	10749.4	10676.6	10312.5
13.0	*10233.9									

SEDIMENT YIELD	=	712.93	tonnes.
PEAK SEDIMENT CONCENTRATION	=	36097.69	mg/l.
TIME TO PEAK SEDIMENT CONCENTRATION	=	12.05	hours.

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********* STORM HYDROGRAPH GENERATED FROM START OF RAINFALL **********

TIME *	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
6.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
7.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
9.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
11.0 *	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1
12.0 *	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0
13.0 *	.0									

INITIAL ABSTRACTION	=	12.70	mm.
ROUTED FLOW TIME FROM THE SUBWATERSHED	=	.00	hours.
TIME TO PEAK OF UNIT HYDROGRAPH	=	.05	hours.
THE DEPTH OF WATER ON WATERSHED	=	63.90	mm.
VOLUME OF RUNOFF	=	.32	thousand cu.m.
PEAK RUNOFF RATE	=	.12	cu. m./sec.
TIME TO PEAK RUNOFF	=	12.05	hours.

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STORM HYDROGRAPH FOR WATERSHED ELLIOT DAM A

TOTAL AREA OF THE WATERSHED	=	.50	ha.
THE DEPTH OF WATER ON WATERSHED	=	63.90	mm.
VOLUME OF RUNOFF	=	.32	thousand cu.m.
PEAK RUNOFF RATE	=	.12	cu. m./sec.
TIME TO PEAK RUNOFF	=	12.05	hours.
TIME INCREMENT OF NEW HYDROGRAPH	=	.20	hours.
NUMBER OF RUNOFF VALUES	=	19	

******* STORM HYDROGRAPH GENERATED FROM START OF RUNOFF *******

.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0	.1	.1	.0	.0	.0	.0	.0	

STORM SEDIMENTGRAPH FOR WATERSHED ELLIOT DAM A

TOTAL SEDIMENT YIELD	=	712.93	tonnes.
PEAK SEDIMENT CONCENTRATION	=	118107.60	mg/l.
TIME TO PEAK SEDIMENT CONCENTRATION	=	12.20	hours.

********* STORM SEDIMENTGRAPH GENERATED FROM START OF RUNOFF ********

1088.3 1219.0 1355.4 1497.4 1644.9 1798.1 1956.9 2121.1 2299.1 3403.0
8771.415996.663458.4********11934.711542.911133.410698.710252.6

PARTICLE SIZE DISTRIBUTION OF SEDIMENT

WEIGHTED SPECIFIC GRAVITY = 2.65

PART. SIZE mm.	% FINER %
.000	.0
.005	5.0
.010	10.0
.050	30.0
.100	40.0
1.000	80.0
10.000	100.0